RADIO-COMMUNICATIONS

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SOLUTIONS TO THEORETICAL AND
EXPERIMENTAL PROBLEMS INTENDED
FOR RADIO ENGINEERS, POST OFFICE
ENGINEERS AND STUDENTS

BY

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PREFACE

THIS book has been prepared, to a large extent for students interested in the City and Guilds of London Institute Examinations, and for this reason part of the introductory chapter has been devoted to Syllabuses of Grade 1, 2, and 3, enumerating the subject matter that the candidate may expect to encounter in the various grades. The Summary of Formulæ at the end of this Chapter is an indispensable feature, and it is essential that every student should make a close study of this section if he wishes to succeed.

There is a good deal of information in the solutions to theoretical and experimental problems given in the book that is certain to prove of real value to Post Office Engineers, Radio Engineers, and indeed to anyone with an interest in the technicalities of Electricity and Radio Communication. The time allowed to answer questions set at the City and Guilds of London Institute examinations is thirty minutes, so every endeavour has been made to model the solutions to questions accordingly. The solutions are not, of course, meant to be just read through; the student should work each problem for himself; comparing his own solution, when complete, with the one given in the book.

It is strongly recommended that any reader with the facilities for so doing, should carry out the experiments detailed in the final chapter, including the plotting of the associated graphs where these are indicated.

W. T. PERKINS.
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CHAPTER I

INTRODUCTORY

CITY AND GUILDS OF LONDON INSTITUTE SYLLABUSES IN RADIO COMMUNICATION

GRADE 1

Questions may be set with the object of testing the candidate's knowledge of the elementary electrical principles applied at this stage of radio-communication, and his ability to deal with problems and calculations based on these principles in addition to the questions more directly concerned with the following subject matter:

1. Construction of transmitting and receiving inductors.

2. Capacitance; construction of fixed and variable condensers for low voltage, fixed condensers for high voltage.

3. Qualitative treatment of eddy current loss including skin effect in conductors, and of dielectric loss in condensers.

4. Construction of two-electrode and three-electrode thermionic valves; principles of action and characteristic curves with application to non-reactive load.

5. Detecting devices for small alternating potentials; contact rectifiers and valves.

6. Construction and action of telephone receivers and electromagnetic loud speakers.

7. High-frequency and low-frequency thermionic amplifiers, essential principles of action. Causes of distortion.

8. Simple circuits of radio receivers including use of retroaction. Qualitative ideas of selectivity.

9. Use of loop aerial for reception and direction finding.

10. Qualitative treatment of simple valve oscillator.

11. Simple wave-meter.

12. General principles of heterodyne reception.

GRADE 2

More difficult questions on the subject-matter of the Grade 1 Syllabus may be set in this examination, in addition to questions on such subjects as the following:

1. Elementary ideas of the radiation and propagation of electromagnetic waves and of the properties of transmitting and receiving antennæ; simple computations neglecting absorption and reflexion.

2. The theory of coupled circuits and their application to the problem of selectivity.

3. The generation of oscillations in a valve circuit. Self-oscillating and master-controlled valve transmitters for C.W. and I.C.W. Neutralising circuits; Simple spark transmitter.

4. The modulation of valve transmitters by keying, tone and speech. Sidebands. Frequency bands necessary for various modulation systems.

5. Construction and action of devices for rectifying alternating current for H.T. supply. Smoothing circuits.

6. Transmitting valves including cooled anode and demountable type valves.

7. The reception of C.W. and I.C.W. telegraphy and of radio-telephony signals, Superheterodyne and super-regenerative receivers Methods of minimising interference from atmospherics and unwanted stations

8. Multi-electrode valves and their uses, including the cathode ray tube.

9. Schematic arrangements and principles of

operation of radio telephone channels connected to landline circuits.

10. High Frequency measurements of current, voltage, resistance, inductance, capacitance, frequency and field strength.

11. Decibel and neper. Simple computations, T and H type of attenuators and their applications, design of simple sections.

12. Interference with radio reception by industrial and domestic electric plant. Devices and circuits for preventing or minimising such interference.

GRADE 3

More difficult questions on the subject-matter of the Grade 1 and 2 Syllabuses may be set in this examination in addition to questions on such subjects as the following:

1. General properties of electro-magnetic waves radiated from an antenna. Polarisation. The effect of the earth and ionosphere on the propagation of radio waves.

2. Simple antenna and antenna arrays for long and short waves. Diversity reception.

3. Radio-frequency transmission lines; inductance, capacitance and characteristic impedance of such lines. Reflexion. Standing waves. Impedance matching.

4. Direction-finding systems for fixed and mobile stations. Causes of error and their elimination. Bellini-Tosi, rotating loop and Adcock systems.

5. Simple treatment of electric wave filters. Image impedance and propagation constant of non-dissipative sections. Design of prototype sections from given formulæ.

6. Constant frequency oscillators including piezo-electric and tuning-fork control. Thermostats. Long and short wave transmitters employing frequency control.

7. The theory of detection using non-linear de-

vices. Distortion in detectors. Frequency changers. Power grid and diode detectors.

8. Intermodulation and distortion in amplifiers, Class A, B and C amplifier. Push-pull amplifiers.

9. The balanced modulator. Suppressed carrier single side-band telephony on long waves. Appropriate transmitting and receiving circuits.

10. The connexion of radio-telephone links to land-line telephone circuits. Technical operation, position and equipment including monitoring amplifier volume indicators, transmission-measuring equipment and singing suppressors of electro-mechanical and thermionic types.

11. Overloading limiting and automatic gain control on receivers.

12. Attenuation equalisers on radio channels and tone control of radio receivers.

13. Electron valve oscillator (Barkhausen effect).

14. Underlying principles of design of high-frequency apparatus and components for transmitting and receiving and measurement purposes, including inductors, condensers, insulators, resistors, attenuators, etc. Special considerations in dealing with high-power stations.

SUMMARY OF FORMULÆ

GENERAL AND D.C. CIRCUITS

Below are given the chief formulæ required in connection with the subjects of electricity and Radio-communication.

1. Resistances in series. $R_T = R_1 + R_2 + R_3$
   R_T is the combined resistance
   and R_1, R_2, R_3 are the resistances so connected.

2. Resistances in parallel $\dfrac{1}{R_T} = \dfrac{1}{R_1} + \dfrac{1}{R_2} + \dfrac{1}{R_3}$

3. Equal resistances in parallel. $R_T = \dfrac{R_1}{n}$

    n is the number of resistors so arranged.

4. Two resistances in parallel. $R_T = \dfrac{R_1 \times R_2}{R_1 + R_2}$

5. Condensers in parallel. $C_T = C_1 + C_2 + C_3$
    C_T is the combined capacity
    and C_1, C_2, C_3 are the condensers so arranged.

6. Condensers in series. $\dfrac{1}{C_T} = \dfrac{1}{C_1} + \dfrac{1}{C_2} + \dfrac{1}{C_3}$

7. Equal condensers in series. $C_T = \dfrac{C_1}{n}$

    n is the number of condensers so arranged.

8. Two condensers in series. $C_T = \dfrac{C_1 \times C_2}{C_1 + C_2}$

9. Inductances in series.
$$L_T = L_1 + L_2 + L_3$$
where L_T is the combined or total inductance.
    L_1, L_2, and L_3 are the respective inductances.

10. Inductances in parallel.
$$\dfrac{1}{L_T} = \dfrac{1}{L_1} + \dfrac{1}{L_2} + \dfrac{1}{L_3}$$

11. Impedances in series.
$$Z_T = Z_1 + Z_2 + Z_3 \text{ etc., ohms.}$$
where Z_T is the combined impedance of the individual
    impedances Z_1 Z_2 and Z_3

12. Impedances in parallel.
$$\dfrac{1}{Z_T} = \dfrac{1}{Z_1} + \dfrac{1}{Z_2} + \dfrac{1}{Z_3}$$

13. Ohm's Law.
$$I = \dfrac{E}{R_T}$$
where I is the current flowing in amperes.
    E is the electromotive force (E.M.F.) in volts.
    R_T is the total resistance of the circuit in ohms.
    $R_T = R + r$ where R and r are the external and
        internal resistance in ohms.

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13a. Power in Watts (P). (D.C. Circuit).

$$P = I^2R \text{ or } E \times I \text{ or } \frac{E^2}{R}$$

14. *Heat dissipated.* (*Calories.*)

$H = 0 \cdot 24\ I^2Rt$ H is the heat dissipated in calories.

or $0 \cdot 24\ EIt$ I is current in amperes.

or $0 \cdot 24\ EQ$ t is time in seconds of current flow.

or $0 \cdot 24\ \dfrac{E^2}{R}\ t$

Q is the quantity (coulombs).

R is the resistance of the circuit.

15. *Work done or energy.* (*Joules.*)

$W = EIt$ or EQ or I^2Rt

or $\dfrac{E^2}{R}t$ $4 \cdot 2$ *joules* $= 1$ *calorie.*

16. The variation in resistance of a wire with temperature.

$$R_t = R_0\ (1 + \propto t)$$

where as in R_t is the resistance of the wire at t^0c.

R^0 ,,   ,,   ,,   ,, 0^0c.

$\propto$,,   temperature coefficient of the material forming the wire.

t ,,   rise in temperature in degrees C.

17. The resistance of a conductor in terms of length and cross sectional area.

$$R = \frac{\rho l}{a}$$

where R is the resistance in ohms.

l ,,   length of the conductor in inches or cms.

a ,,   area of cross section in square inches or square cm.

ρ ,,   specific resistance or resistivity o f the conductor material.

18. Measurement of resistance by the Wheatstone Bridge.

$$x = \frac{ad}{b} \text{ ohms.}$$

where a and b are the ratio arms
d is the known variable resistance
x is the unknown resistance.

19.   Secondary cell charging.

$$I = \frac{E - e}{R + r}$$

where R is the variable circuit resistance.

r is internal resistance of the battery.

I is the charging current.

E is the charging voltage.

e is the back E.M.F. of the cells.

$e = ne_1$.

n is the number of cells to be charged.

$e_1 = 2 \cdot 1$ volts at commencement of charge and $2 \cdot 5$ volts at the end of charge.

COILS AND TRANSFORMERS

20.   The inductance of a coil or circuit.

$$L = \frac{4\pi t^2 \mu a}{10l} \times 10^{-8} = \frac{1 \cdot 257\, t^2 \mu a}{l} \times 10^{-8} \text{ henrys}$$

where t is the number of turns.

μ is the permeability.

a is the area of cross section of the magnetic circuit.

l is the length of the magnetic circuit.

L is the inductance in henrys.

21.   Inductance of a coil.

$$L = \frac{E}{\dfrac{I_2 - I_1}{t}} \text{ henrys.}$$

where E is the e.m.f. induced in the coil.

t is the time in seconds for the current to change from I_1 to I_2 in the coil.

$I_2 - I_1$ is the current change in amperes.

22.   The Q value or magnification factor of a coil or circuit.

$$Q = \frac{\omega L}{R} \qquad \text{where } \omega = 2\pi f$$

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f is the frequency in c.p.s.

L is the inductance in henrys.

R is the resistance in ohms.

23. Self-capacitance of a single-layer coil.

$$C = 0.5R \text{ to } 0.75\ R \quad \mu\mu F$$

where R is the radius of the coil in cm.

24. Self-capacitance of a double-layer coil.

$$C = \frac{0.18\ K\ R\ L}{d}\ \mu\mu F$$

where R is the radius in cms.

L is the length in cms.

D is the distance between layers.

25. The coefficient of Coupling (Inductive).

Is the ratio $\dfrac{M}{\sqrt{L_1\ L_2}}$

where M is the mutual inductance.

L_1 ,, inductance of the primary coil.

L_2 ,, ,, ,, secondary coil.

26. Length of wire required for winding an electro-magnet (circular bobbin).

(a) $$l = 2\ \pi n p q$$

where l is the length of wire.

n is the number of turns.

p is the number of layers.

q is the mean radius.

(b) $$l = \frac{\pi h}{4d^2}\ (D_2{}^2 - D_1{}^2)$$

where l is the length of the wire.

d is the diameter of the wire.

h is the distance between the cheeks of the electromagnet.

D_1 is the diameter of the core.

D_2 is the diameter of the outer winding.

27. Energy stored in a coil.

$$W = \frac{I^2 L}{2}\ \text{joules.}$$

where I is the current in amperes.

L is the inductance in henries.

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28. Force on a conductor in a magnetic field. (Application moving coil instruments.)

$$F = \frac{BlI}{9810} \text{ grammes.}$$

where B is the density of the field in lines per sq. cm.

l is the length of the conductor in the magnetic field.

I is the current flowing in the conductor in amps.

29. E.M.F. induced in a coil in a magnetic field. (Application moving coil instrument.)

$$E = \frac{\Phi T}{10^8 t} \text{ volts.}$$

where Φ is the change in the lines of force linked with the coil.

T is the total number of turns in the coil.

t is the time in seconds for the linking to take place.

E is the E.M.F. induced in the coil.

30.   TRANSFORMERS.

$$\text{Voltage ratio} = \frac{\text{Secondary turns}}{\text{Primary turns}}$$

$$\text{Current ratio} = \frac{\text{Primary turns}}{\text{Secondary turns}}$$

Output voltage = Input voltage × voltage ratio

Output current = Input current × current ratio.

31. Efficiency of a transformer.

$$\text{Efficiency} = \frac{\text{Output Watts}}{\text{Input Watts}} \times 100 \text{ per cent.}$$

$$,, \quad \frac{\text{Output}}{\text{Output + losses}} \times 100 \text{ per cent.}$$

32. Power absorbed by a transformer on open circuit

$$P = E \times I \; Cos \; \theta$$

where E and I are the primary voltage and current.

$Cos \; \theta$ is the power factor.

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33. **Copper losses in a simple transformer.**
$$I^2_p R_p + I^2_s R_s \text{ watts.}$$
where I_p is the primary current in amperes.

R_p is the resistance of the primary coil in ohms.

I_s is the secondary current in amperes.

R_p is the resistance of the secondary coil in ohms.

CONDENSERS

34. **Capacitance of a parallel plate condenser.**
$$C = \frac{AKN}{4\pi d} \text{ Electrostatic Units (}Esu\text{)}$$
where A is the area of one plate.

N is the number of dielectrics

d is the distance between the plates or the thickness of the dielectric.

and K is the dielectric constant or permittivity

c is the capacitance.

Since 1 microfarad $= 9 \times 10^5$ Electro static Units
$$C = \frac{A\ K\ N}{4\pi d \times 9 \times 10^5} \mu F$$
$$= \frac{AKN \times 10^6}{4\mu d \times 9 \times 10^5} = \frac{1 \cdot 11\ AKN}{4\pi d} \mu\mu F$$

35. **Capacitance of a cylindrical condenser.**
$$C = \frac{0 \cdot 24\ Kl}{\log_{10} R/r} \mu\mu F$$
where l is the axial length in con.

R is the cylinder outer radius.

r is the cylinder inner radius.

36. **The charge stored in a condenser Q.**
$$Q = VC \text{ Coulombs.}$$
$$\therefore V = \frac{Q}{C}$$
$$\text{and} \quad C = \frac{Q}{V}$$

where Q is the charge in Coulombs.

C is the capacitance in farads.

V is the potential difference between the plates.

37. Dielectric strength of a condenser.

$$Dielectric\ strength\ =\ \frac{Breakdown\ Voltage}{Distance\ between\ plates}$$

8. Energy stored in a condenser.

$$W = \frac{QV}{2}\ joules.$$

where V is the potential difference between the plates in volts.

or $\dfrac{V^2C}{2}$ C is the capacity in farads

or $\dfrac{Q}{2C}$ Q is the charge in coulombs.

39. Variation of capacitance of a tuning condenser with the angle of overlap θ of the plates.

Straight line capacity type $C \propto \theta$

Straight line frequency type $C \propto \dfrac{1}{\theta^2}$

Straight line wavelength type $C \propto \theta^2$

40. **A.C. CIRCUITS**

$$I = \frac{E}{Z}$$

where I is the current in amperes.

Z is the impedance of the circuit.

E is the E.M.F. in volts.

41. Impedance. Series A.C. Circuit.

Impedance $Z = \sqrt{R^2 + X^2}$

where X is the reactance in ohms.

R is the ohmic resistance.

42. Capacitive reactance. Inductive reactance.

$$X_c = \frac{1}{\omega C} \qquad\qquad X_L = \omega L$$

where ω is the angular velocity.

$\omega = 2\pi f$

f is the frequency in c.p.s.

C is the capacitance in farads.

L is the inductance in henries.

43. Reactance with L and C in circuit.

$$X = \left(\omega L - \frac{1}{\omega C}\right)$$

44. Impedance of series circuit.

$Z_1 = \sqrt{R^2 + (\omega L)^2}$ with resistance and inductance.

$Z_2 = \sqrt{R^2 + \left(\frac{1}{\omega C}\right)^2}$ with resistance and capacitance.

$Z_3 = \sqrt{R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2}$ with resistance, inductance and capacitance.

45. Current flowing in a series circuit.

$I = \dfrac{E}{Z_1} = \dfrac{E}{\sqrt{R^2 + (\omega L)^2}}$ with resistance and inductance.

or $= \dfrac{E}{Z_2} = \dfrac{E}{\sqrt{R^2 + \left(\frac{1}{\omega C}\right)^2}}$ with resistance and capacitance.

or $\dfrac{E}{Z_3} = \dfrac{E}{\sqrt{R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2}}$ with resistance, inductance and capacitance.

46. Resonance of an A.C. series circuit.

$\omega L = \dfrac{1}{\omega C}$ i.e. the respective reactances cancel out and the current is a maximum.

$I = \dfrac{E}{R}$

47. Resonant frequency $f_r = \dfrac{1}{2\pi\sqrt{LC}}$

48. Current in a parallel circuit.

(a) $I = \sqrt{I_R^2 + I_L^2} = \sqrt{\left(\dfrac{V}{R}\right)^2 + \left(\dfrac{V}{\omega L}\right)^2}$

$= V\sqrt{\dfrac{1}{R^2} + \dfrac{1}{(\omega L)^2}}$

Resistance and inductance in parallel

$$(b) \; I = \sqrt{I_R{}^2 + I_0{}^2} = \sqrt{\left(\frac{V}{R}\right)^2 + \left(\frac{V}{\frac{1}{\omega C}}\right)^2}$$

$$= V \sqrt{\frac{1}{R^2} + \omega^2 C^2}$$

Resistance and capacitance in parallel.

49. Phase angles.
   The angle of lag of current on voltage in (a) is given by θ

$$\text{where } \tan \theta = \frac{R}{\omega L}$$

The angle of lead in (b) is given by $\tan \theta = \omega C R$

50. Power in an A.C. series circuit.
$$P = E \times I \; \text{Cos} \; \theta$$
where Cos θ is the power factor and E and I are R.M.S. values.

51. Power factor of an A.C. circuit
$$\text{Cos} \; \theta = \frac{\text{true Watts}}{\text{apparent Watts}} = \frac{R}{Z}$$

52. Current taken by a condenser.
$$I = \omega \; C \; E$$

53. Root Mean Square (R.M.S.) values of current and voltage of a sine wave
$$I_{rms.} = 0 \cdot 707 \; I_{Max}$$
$$E_{rms.} = 0 \cdot 707 \; E_{Max}$$
where I_{Max} and E_{Max} are the maximum values of current and voltage of the sine wave respectively.

54. Measurement of Frequency in terms of wavelength and velocity of propagation.
$$Frequency = \frac{Velocity \; of \; propagation}{Wavelength}$$

$$f = \frac{v}{\lambda}$$

$$\therefore \lambda = \frac{v}{f}$$

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and $v = \lambda f$

where f is the frequency in c.p.s.
λ is the wavelength.
V is the velocity of propogation using the same units of distance as λ.

55. Resonant frequency.

$$f_r = \frac{159\cdot2}{\sqrt{LC}} \text{ Kc/s.}$$

$$= \frac{3 \times 10^5}{\lambda}$$

and $\lambda = 1885 \sqrt{LC}$

Since $V = \lambda f_r$

$$V = 3 \times 10^5$$

where f_r is the resonant frequency.
λ is the wavelength in metres.
L is the inductance in microhenries.
C is the capacitance in microfarads.
V is the velocity of propagation metres/sec.

56. The natural frequency of an X cut quartz crystal.

$$f = \frac{2\cdot860}{t} \text{ Kc/s.}$$

where t is the thickness of the crystal in mm.

VALVES

57. The emission from the filament varies with the heating current and obeys very closely the following law:

$$i = AT^2 e^{\frac{-b}{T}}$$

where i is the electron emission in amperes/square cm.
T is the temperature in degress absolute.
A and b are constants which are characteristic of the cathode material.
e is the base of Naperian logs. $2\cdot7183$
For pure tungsten $A = 30$ and $b = 52,400$.
Thoriated tungsten $A = 3$ and $b = 30,500$.

58. The three-halves power law.

The rise in anode current I_a, with fixed filament temperature and increasing anode voltage, follows a curve of the form shown in Fig. 23 and is found to follow the law

$$I_a = \frac{K}{r} \times V a^{\frac{3}{2}}$$

where V_a is the anode voltage.

$\quad I_a$ is the anode current.

$\quad r$ is the radius of the cylindrical anode surrounding the filament.

$\quad K$ is a numerical factor.

59. Mutual Conductance of a valve. (g_m).

$$g_m = \frac{Small\ change\ in\ anode\ current}{Change\ in\ grid\ volts\ to\ produce\ anode\ current\ change.}$$

$$= \frac{dIa}{dVg}\ with\ anode\ voltage\ constant$$

60. The anode characteristic A.C. resistance of a valve (δa).

$$\delta a = \frac{Change\ in\ anode\ volts}{Change\ in\ anode\ current\ in\ amps.} \quad \text{Ohms. (Grid volts constant.)}$$

$$\delta a = \frac{\mu}{g_m}$$

$\quad$ where μ $\quad$ is the amplification factor of the valve.

$\quad g_m$ is the mutual conductance of the valve

61. Amplification Factor of a valve (μ).

$$\mu = \delta_a \times g_m$$

62. Voltage amplification across a non-inductive load resistance.

$$m = \frac{\mu R}{R + \rho_a}$$

where μ is the amplification factor

$\quad R$ is the load resistance

and δ_a is the anode A.C. resistance.

The gain in decibels equals $20 \log_{10} m$.

63. Voltage amplification across an inductive load (neglecting resistance).

$$M = \frac{\mu \omega L}{\sqrt{\mu_a + \omega L}} \quad \text{where } L \text{ is the Inductance of the coil.}$$

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64. Voltage amplification when the load comprises inductance and resistance.

$$M = \mu \sqrt{\frac{R^2 + (\omega L)^2}{(\delta_a + R)^2 + (\omega L)^2}}$$

65. Voltage amplification with transformer coupling

$$M = \frac{\mu R T}{R + \delta_a T^2}$$

where T is the transformation ratio.

R is the resistance of the secondary winding.

The above formula assumes a perfect condenser having unity coupling factor and a non-inductive load.

66. Voltage drop across the anode load resistance of a valve.

$$V = I_a R$$

where I_a is the anode current in amperes.

R is the anode load resistance in ohms.

67. Voltage amplification with tuned anode at resonance.

$$M = \frac{\mu L}{\delta_a C R + L}$$

when C is the capacitance of the tuned circuit.

L is the inductance of the tuned circuit.

68. Power amplification.

To enable a maximum power output from the valve to be obtained the anode load resistance should equal the anode characteristic resistance, i.e. $\delta_a = R$.

To obtain maximum undistorted output R should equal $2\rho_a$.

When the load resistance R is coupled to the anode by a transformer, maximum output is obtained when

$$R = \frac{\delta_a}{T}$$

where T is the transformer ratio.

and for maximum undistorted output the transformer ratio

$$T = \sqrt{\frac{2\delta_a}{R}}$$

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69. Inter-electrode capacity (approximate values).
Triode: Between grid and anode 5 $\mu\mu F$
Tetrode: ,,   control grid and anode 0·003 $\mu\mu F$
(with S.G. earthed to R.F.).

70. Total space current. (Tetrode.)
Total space current $= I_a + I_s$
where I_a is the anode current.
I_s is the screen grid current.

71. Amplitude modulation (Upper and lower side-bands).

When a carrier wave having a frequency f is modulated by a wave having a frequency f_1 then the upper side-band frequency $= f + f_1$ and the lower side-band $f - f_1$.

AERIALS

72. Field strength of a distant transmitter.

$$F = \frac{377\, h\, I}{\lambda d} \text{ volts per metre.}$$

where I is the aerial current in amps.
d is the distance away in metres of the transmitter.
h is the effective height of the aerial in metres.
λ is the wavelength in metres.

73. The voltage induced in a receiving aerial.
$$E = Fh \text{ volts.}$$
where h is the effective height of the aerial.
and F is the field strength in volts per metre.

74. The received current will be
$$I = \frac{Fh}{R}$$

where R is the resistance of the circuit in ohms.

75. The voltage induced in a frame aerial in the plane of propagation of the wave is given by:
$$E = \frac{2\pi\, F\, A\, N}{\lambda} \text{ volts}$$
where A is the frame area in square metres.
N is the number of turns.
λ is a wavelength in metres.

76. Voltage received in a frame aerial which is not in the direction of propagation.

$$E = \text{Cos } \theta \left(\frac{2\pi \, F \, A \, N}{\lambda} \right) \text{ volts.}$$

where θ is the angle between the plane of the frame and the direction of propagation.

77. Voltage induced in a frame aerial.
$$E = hF \text{ Cos } \theta$$

78. The radiation resistance of an aerial
$$r = \frac{1584 \, h^2}{\lambda^2} \text{ ohms.}$$

where h is the effective height
λ is the wavelength in the same units as h
r is the radiation resistance in ohms
$r = 1.76 \, h^2 f^2 \times 10^{-8}$ ohms
h is measured in metres
and f the frequency in kilocycles.

79. Power radiated by an aerial.
$$P = I^2 r \text{ watts.}$$
where I is the aerial current in amps.
and r is the radiation resistance.

$$P = \frac{1584 \, h^2 I^2}{\lambda^2} \text{ watts.}$$

80. Radiation resistance.
$$r = \frac{P}{I^2}$$

81. Aerial efficiency.

$$\text{Efficiency} = \frac{r}{R} \times 100 \text{ per cent.}$$

where r is the radiation resistance.
and R is the aerial resistance.

82. Radiation constant.
Radiation constant $= hI$ metre-amperes.
where h is the effective height of the aerial.
I is the aerial current in amps.

83. Frequency band required for a picture to be scanned along its longer dimension is given by

$$f = \frac{\rho l^2 r}{2}$$

where l is the number of scanning lines per picture

ρ is the number of picture repetitions

and r is the ratio of longer to shorter dimensions of the picture.

LINE TRANSMISSION

84. The current received at the end of a transmission line.

$$I_r = I_s e^{-\alpha} \quad \ldots \ldots \ldots \ldots (i)$$

where I_r is the received current.

I_s is the sent current.

l is the length of the transmission line.

$e = 2 \cdot 7183$.

α is the attentuation constant.

From (i) $\alpha \cdot l = log \dfrac{I_s}{I_r} = 2 \cdot 303 \; log_{10} \dfrac{I_s}{I_r} \ldots \ldots (ii)$

$$\alpha l = 1 \cdot 151 \; log_{10} \frac{P_s}{P_r} \quad \ldots \ldots \ldots \ldots (iii)$$

Where P_s and P_r are the power sent and received.

85. The cut-off frequency of electric wave filters. (Low or High pass.)

$$f_c = \frac{1}{2\pi \sqrt{LC}}$$

where for a low pass filter

L is the series inductance in henries per half section.

C is the shunt capacitance in farads per half section,

and for a high pass filter

C is the series capacitance per half section.

L is the shunt inductance per half section.

86. The characteristic resistance $Ro =$
$$\sqrt{\left(\dfrac{k}{2}\right)^{2} + \dfrac{R}{G}}$$

$$Ro = \sqrt{\left(\tfrac{R}{2}\right)^{2} + \tfrac{R}{G}}$$
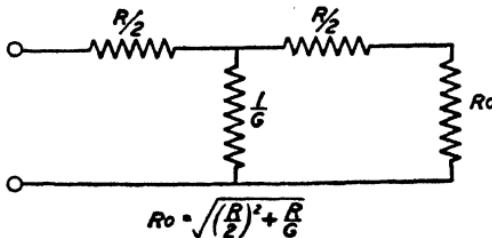
87. The characteristic resistance $Ro = \sqrt{R_f \times R_c}$
where R_f is the measured resistance with the far
end open.
R_c is the measured resistance with the far
end closed
and the characteristic impedance $Zo = \sqrt{Z_f \times Z_c}$

88. To convert from T to π Network or vice versa.

T NETWORK

π   NETWORK

$$R_4 = \dfrac{R_o{}^{2}}{R_1}$$

$$R_5 = \dfrac{R_o{}^{2}}{R_2}$$

$$R_1 = \dfrac{R_o{}^{2}}{R_4}$$

$$R_2 = \dfrac{R_o{}^{2}}{R_3}$$
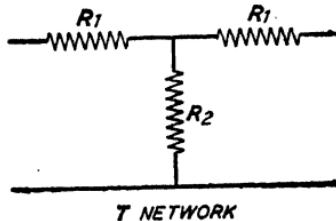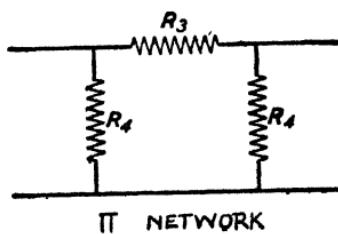
89. Considering Power Ratios	Attenuation in nepers	$\frac{1}{2} \log_e \frac{P_s}{P_r}$
	,, ,, bels	$\log_{10} \frac{P_s}{P_r}$
	,, ,, decibels	$10 \log_{10} \frac{P_s}{P_r}$

90. Considering Voltage Ratios	Attenuation in nepers	$\log_e \frac{V_s}{V_r}$
	,, bels	$2 \log_{10} \frac{V_s}{V_r}$
	,, ,, decibels	$20 \log_{10} \frac{V_s}{V_r}$

91. Considering Current Ratios	Attenuation in nepers	$\log_e \frac{I_s}{I_r}$
	,, ,, bels	$2 \log_{10} \frac{I_s}{I_r}$
	,, ,, decibels	$20 \log_{10} \frac{I_s}{I_r}$

1 neper $= 8\cdot686$ db 1 bel $= 1\cdot1513$ nepers.

Method of converting common logs to Naperian logs.

$\log_{10} N = \log_e N \times 0\cdot4343$ or conversely

$\log_e N = \log_{10} N \times 2\cdot3026.$

CHAPTER II

COMPONENTS

Discuss two of the most common types of fixed resistor used in modern radio equipment, referring to their relative advantages.

What effect has a rise in temperature on the resistance value of a length of resistance wire?

Two of the most common forms of fixed resistor in general use are (*a*) the carbon-rod type; (*b*) the wire-wound type.

The carbon-rod resistor consists of a rod of resistive material, usually a mixture of clay and carbon, baked at a high temperature and fitted with end caps or wires to afford connection.

The value of the resistor is determined by its cross-sectional area and length.

This type of resistor is obtainable in a very wide range of values, and may be constructed to dissipate between one and three watts of power, the power being generated within the resistor in the form of heat.

The wire-wound resistor is employed where it is necessary to dissipate more energy or when small values of resistance are required.

This type takes the form of a winding of special resistance wire, an alloy in the main of copper, iron and nickel, on a former of clay, asbestos or other insulating, heat-resisting material. Again end-caps or wires are fitted for connecting purposes. The value of the resistor is in this case determined by the chemical constitution, cross-sectional area, and length of the resistance wire used. Wire-wound resistors are obtainable for all values of resistance, but are most commonly used for values lower than 2000 ohms where more than three watts of power must be dissipated.

Use of the carbon-rod resistor is to be preferred where little power is involved, as it possesses practically no self-inductance and capacitance, in addition to its relatively low cost. Where considerable power must be handled, the wire-wound resistor is preferable in spite of its high self-inductance and capacitance. The former may be reduced by winding half of the resistance wire in one direction, and the remainder in the opposite direction (bifilar wound).

A rise in the temperature of a length of resistance wire will cause the value of its resistance to rise by an amount depending upon the temperature coefficient of the material from which the wire is made, and the temperature rise in degrees Centigrade.

Thus. $R_t = R_0(\text{I} + \propto t)$

where R_t is the resistance at t^0C.

R_0 is the resistance at 0^0C.

$\propto$ is the temperature coefficient.

t is the rise in temperature in degrees centigrade.

Describe one simple method of determining the value of an unknown resistance.

The substitution method is one of the simplest ways of determining accurately the value of an unknown resistance. The apparatus required consists of a battery, an ammeter, a key and a high-grade variable known resistance. Fig. I shows the manner in which this apparatus should be connected. With the key in position A the current flowing in the milliammeter should be noted (I_1). The key should then be thrown to position B and the high-grade variable resistance adjusted until the current flowing in the circuit is the same as previously. Under these conditions the unknown resistance Rx equals the variable resistance Rv, the latter being ascertained from the reading of the dials.

Milliammeter

Battery

FIG. 1.
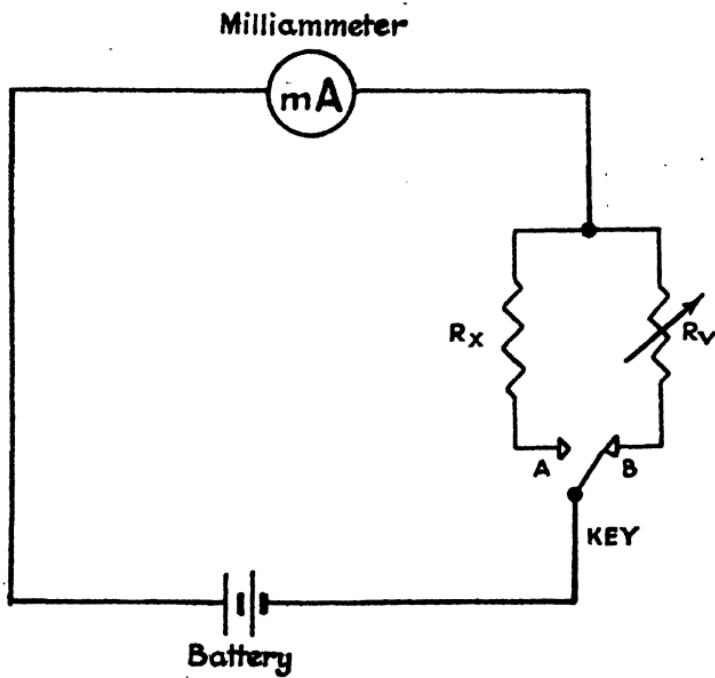
Describe the construction of one type of low-voltage fixed condenser suitable for use in (a) the audio-frequency; (b) the radio-frequency stages of wireless equipment.

Condensers of the waxed or oiled paper type are quite suitable for use in the audio-frequency stages of radio equipment, i.e. as coupling and by-pass condensers, etc.

The waxed paper condenser is made from thin strips of specially-prepared paper and metal foil arranged as shown in Fig. 2.

The two strips of paper and foil are wound up to form a roll, the projecting edges of the two strips of foil being crimped together and joined to the connectors.

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The roll of paper and foil is immersed in boiling wax or oil in vacuo to exclude all moisture, after which it is sealed in an airtight container of waxed cardboard or bakelite. Connection is made by means of wire ends or screw terminals.

The above method of construction is adopted to overcome inductive and resistive losses experienced in earlier types, where connection to the foil strips was made only at one end.

The waxed paper condenser as described above is unsuitable for use in the radio-frequency stages of wireless equipment owing to inductve losses prevalent at these frequencies.


WAXED PAPER STRIPS

FOIL STRIPS
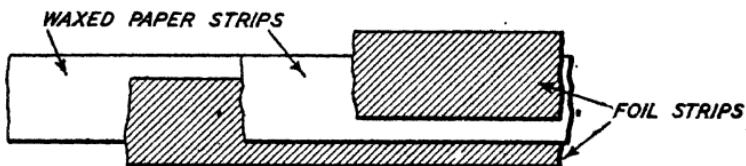
FIG. 2.

The condensers normally employed for radio-frequency work are of the silver-mica or silver-ceramic type, since these possess high stability combined with extremely low losses.

These condensers are made by depositing a very thin film of silver directly on to both sides of a thin strip of mica or ceramic base material. The treated strip is then mounted in a moulding of bakelite or ceramic base material, wire ends being fitted to permit connection.

What type of condenser would you employ in the smoothing circuit of a high-tension power unit? Describe its construction.

A condenser suitable for use in the smoothing circuit of a high-tension power unit would be of the electrolytic type, either wet or dry, since this type is efficient,

compact, reasonably inexpensive, and especially suitable for circuits where a D.C. potential with a superimposed A.C. component is to be dealt with.

The wet electrolytic consists of an aluminium or copper container, usually of cylindrical formation inside which is fitted an aluminium tube or anode, the intervening space being filled with a solution of ammonium or sodium borate, which forms the cathode. One end of the container is terminated in a coarse screw-thread to permit mounting and afford connection to the cathode. Connection to the anode is effected by means of a screw passing through an insulating bush in the mounting. The arrangements are illustrated in Fig. 3.


ALUMINIUM OR COPPER CONTAINER

ALUMINIUM CYLINDER (ANODE)

SOLUTION OF ALUMINIUM OR SODIUM BORATE (CATHODE)

FIXING NUT (ALSO PROVIDING CONNECTION TO CATHODE)

ANODE CONNECTION

FIG. 3.

Some form of safety valve is usually incorporated to prevent fracture of the container, should a fault develop.

The action of the condenser is as follows:

Application of a positive D.C. potential to the anode causes a very thin film, usually described as aluminium oxide, to form on the plate by a chemical action which is not fully understood. The aluminium oxide is an insulator, and thus the arrangement functions as a condenser, the liquid in contact with the container forming the other electrode. The film is so thin that the capacitance of the condenser is very high compared with the capacitance which could be obtained in a similar space by other methods.

The capacitance depends largely on the forming voltage, an applied potential of 500 volts will produce a capacitance of some 1·0 to 1·5 microfarad per square
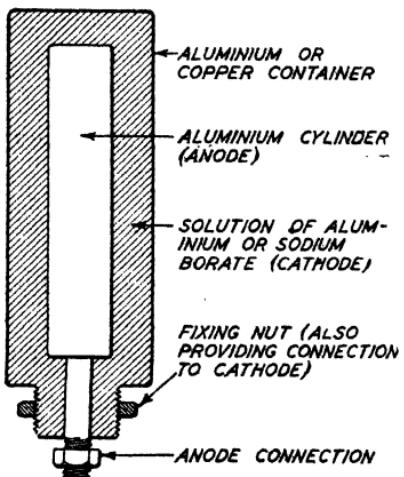
inch of anode surface. Application of the D.C. voltage is accompanied at first by a heavy leakage current which falls as the capacitance rises, to a very low value. Disconnection of the polarising potential causes disintegration of the aluminium oxide film.

The dry electrolytic condenser is made by winding together two strips of aluminium foil one of which, the anode, has a film of aluminium oxide formed on one side, with a separator of impregnated muslin, the whole being housed in a waxed cardboard container. Connection to the electrodes is normally made by means of insulated flexible wire "tails".

What are the relative advantages and disadvantages of:
  (a) An electrolytic condenser compared with a mica condenser?
  (b) Paper compared with air as the dielectric of a condenser.

Advantages of the electrolytic condenser compared with mica condenser are:
  (1) For capacitances above $2\mu F$ it is cheaper to produce electrolytic condensers.
  (2) Greater capacitance can be obtained in a given space with electrolytic condensers.
  (3) The electrolytic will withstand a temporary overload and then, when normal working conditions are restored, be unimpaired, i.e. the punctured dielectric heals itself.

Disadvantages of the electrolytic condenser.
  (1) The capacitance of this type of condenser decreases with age while that of the mica condenser remains constant, throughout its life.
  (2) The electrolytic condenser allows a leakage current to flow between its terminals. In circuits where this would be harmful mica condensers could be used successfully.
  (3) The electrolytic condenser is constructed so that it will only pass current in one direction, it

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cannot therefore be used for general alternating current work.

The relative advantages of paper as compared with air as a dielectric are:

(1) Paper has a higher dielectric strength, therefore with a specified voltage the plates can be placed nearer together.

(2) Greater capacitance can be obtained in a given space due to the higher dielectric constant of paper.

(3) The use of paper enables the plates to be made of thin metal foil if required. This is useful in the case of large condensers. Rigid plates must be used if air is the dielectric.

The disadvantages of paper are:

(1) The dielectric loss in paper is greater than air. This also gives the paper condenser a worse power factor.

(2) The insulation resistance of paper may not be so high as air, and consequently a paper condenser may have a worse power factor.

Describe the construction of variable tuning condensers suitable for use at medium radio frequencies. What is the chief difference in construction of the square-law and log-law types?

The major components of a variable air-spaced tuning condenser are (a) a bank of fixed plates; (b) a bank of moving plates which may be rotated so that the extent of overlap with the fixed plates may be varied and (c) a framework to support the fixed plates and provide bearings for the rotating vanes.

The metal used in the manufacture of plates for condensers suitable for all radio frequencies is normally brass or aluminium, but the material used for the end plates depends on the frequency range for which the condenser is designed. Condensers for low frequencies have end plates of ebonite or similar material, but as these introduce losses at medium frequencies, end plates

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of condensers for this range are usually of metal. End plates of condensers designed for high frequencies, i.e. short waves, are made from ceramic base insulating material, the amount of material used being reduced to a minimum.

The fixed plates of medium frequency condensers are held rigidly in their correct position by small strips or tubes of insulating material which are clamped between the end plates. The rotating vanes are bolted to the spindle, the bearings for which are mounted on the metal end plates. Some manufacturers depend on the bearings themselves to provide electrical connection with the moving plates, but as this arrangement is liable to produce noises during rotation a flexible pigtail connection, by-passing the bearings, is to be preferred.
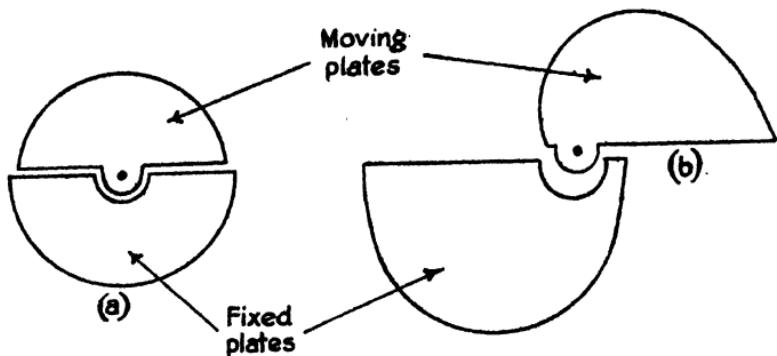

FIG. 4.

The capacitance of earlier variable condensers having semi-circular plates was directly proportional to the angle of overlap (Fig. 4 (a)). This was found to be unsatisfactory when used in radio receivers as extremities of the wavelength range were cramped, since the wavelength to which the circuit tunes is proportional to the square root of the capacity.

To overcome this cramping, the shape of the plates was altered so that the capacitance increased as the square of the angle of overlap, the wave-length in this case being directly proportional to the dial setting.

This type of condenser is known as the square-law or straight-line-wave-length type. Fig. 4 (b).

With the increase in the number of broadcasting stations, it was found that the square law type was still not fully satisfactory since stations were now distributed over the available range on a frequency basis. Further improvement has been obtained by again changing the shape of the plates so that the rate of increase in capacity at any angle of overlap is proportional to the capacity at the particular angle. This spreads the tuning range more evenly over the whole of the condenser dial, and is found to be more convenient for the ganging of condensers in multi-stage receivers. This type is known as the log-law or mid-line type.

It will be seen from the foregoing that the chief difference in the construction of square-law and log-law condensers is to be found in the shape of the plates.

Explain the following terms with regard to a condenser. (a) Leakage loss; (b) Dielectric absorption; (c) Conductor loss.

These are three losses that occur in condensers.

(*a*) Leakage losses can be divided thus:

  (1) Leakage of the charge from the edges of the plates.

  (2) Leakage due to the dielectric having a low insulation resistance.

(*b*) Dielectric absorption is a loss caused by a dielectric that absorbs or retains a portion of its charge when condenser is discharged, This type of loss only occurs in solid or liquid dielectrics.

(*c*) Conductor losses in a condenser are due solely to the ohmic resistance of the plates and leads of the condenser. To keep this loss at a minimum, leads to the condenser should be short, and poor joints should be avoided.

***Explain the meaning of the following terms.
By-pass Condenser, Coupling Condenser and Grid
Condenser.***

By-pass Condenser.

As its name suggests, a by-pass condenser provides
a low impedance path to the high frequency oscillations
thus preventing a loss of power which would otherwise
occur if the oscillations were to traverse a path of high
impedance. The capacitance of a condenser used in
the above manner will be dependent upon the fre-
quency. Typical values being from $0 \cdot 0003 \; \mu F$ to
$0 \cdot 01 \mu F$.

Coupling Condenser.

A coupling condenser serves to transfer a radio
frequency voltage from one point to another, whilst
preventing a direct current flow. The voltage across
such a condenser is the sum of the peak radio-fre-
quency and the high-tension voltages and it must be
chosen accordingly. The capacitance of the con-
denser used in this manner will depend upon the
frequency and the position the condenser occupies,
i.e. whether it is placed at points of high radio-fre-
quency voltage or otherwise.

Grid Condenser.

In grid rectification a condenser enables the grid of
the valve to become negatively charged and prevents
the charge being instantaneously reduced through the
tuned circuit. A resistor which is placed in parallel
with this condenser enables the charge to leak away
slowly and as the time taken for this action is important
the correct capacitance of the condenser is essential.

Approximate values for grid condensers are about
$0 \cdot 001 \mu f.$ for high frequencies and about $0 \cdot 00005 \; \mu f.$
for ultra high frequencies.

***Three condensers have capacities of 2 $\mu F.$,
3 $\mu F.$ and 4 $\mu F.$ Calculate their combined
capacity when they are connected:***
   (a) In series.

(b) *In parallel.*
**(c) *The 4 μF. condenser connected in series
with the 2 μF. and 3 μF. condensers con-
nected in parallel.***

Fig. 5 shows the condensers connected in the three
different ways mentioned.


(a) —|²|—|³|—|⁴|—

(b)

(c)
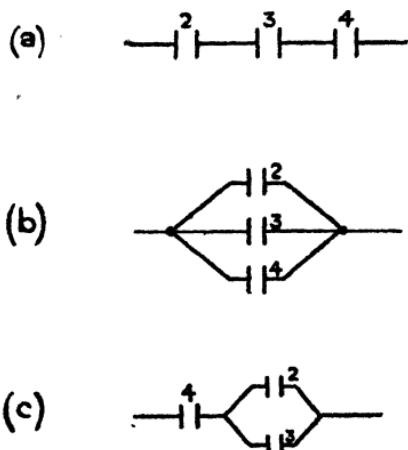
FIG. 5.

(a) The combined capacity of a number of condensers
connected in series is given by the formula.

$$C_T = \frac{1}{\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}}$$

where C_T is the combined capacity
and C_1, C_2, C_3 are the capacities of the indivi-
dual condensers.

$$\therefore \frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$

$$= \frac{1}{2} + \frac{1}{3} + \frac{1}{4} = \frac{6 + 4 + 3}{12} = \frac{13}{12}$$

$$\therefore C_T = \frac{12}{13} \mu F.$$

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(*b*) The combined capacitance of a number of condensers in parallel is the sum of the individual capacitances, thus
$$C_T = C_1 + C_2 + C_3 = 2 + 3 + 4 = 9 \mu F.$$

(*c*) The combined capacitance of the two condensers in parallel is $2 + 3 = 5 \mu F$. This capacity is in series with $4 \mu F$. (sketch *c*). The combined capacity will be

$$C_T = \dfrac{1}{\dfrac{1}{4} + \dfrac{1}{5}}$$

$$\therefore \dfrac{1}{C_T} = \dfrac{1}{5} + \dfrac{1}{4} = \dfrac{4 + 5}{20} = \dfrac{9}{20} \quad \therefore C_T = \dfrac{20}{9} = 2 \cdot 2 \, \mu F$$

Answers (*a*) $\dfrac{12}{13} \mu F.$

(*e*) $9 \ \mu F.$
(*c*) $2 \cdot 2 \ \mu F.$

State the formula used for estimating the energy stored in a condenser.

Find the energy stored in a condenser in each of the following cases:

> (**1**) **When the charge is 2 coulombs and the potential between the plates 50 volts.**
>
> (**2**) **When the capacity is 2 farads and the potential between the plates is 10 volts.**
>
> (**3**) **When the charge is 1 coulomb and the capacity is 1 farad.**

The energy stored in a condenser can be determined by either of the following formulæ:

$$W = \dfrac{QV}{2} \text{ joules (1)}$$

$$W = \dfrac{V^2 C}{2} \text{ joules (2)}$$

$$W = \dfrac{Q^2}{2C} \text{ joules (3)}$$

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where W is the energy stored in joules.

Q is the charge in coulombs.

V is the potential in volts between the plates.

C is the capacity in farads.

Energy stored in case (1)

$$W = \frac{QV}{2} = \frac{2 \times 50}{2} = 50 \text{ joules.}$$

Energy stored in case (2)

$$W = \frac{V^2 C}{2} = \frac{2 \times 100}{2} = 100 \text{ joules.}$$

Energy stored in case (3)

$$W = \frac{Q^2}{2C} = \frac{1}{2 \times 1} = 0 \cdot 5 \text{ joule.}$$

Upon what characteristics does the capacitance of a parallel plate condenser depend? State the formula used for determining the capacitance of any type of parallel plate condenser. What is the energy stored in a 0·5 μf. condenser when it receives a charge of 40 microcoulombs?

The capacitance of a parallel plate condenser varies directly as the size and number of plates in parallel, and varies inversely as their distance apart.

where A is the total effective plate area.

i.e. $A = a \times n$

$$C \propto \frac{A}{d} \quad \text{where } a = \text{area of one plate.}$$

$n =$ number of dielectrics.

$d =$ distance between plates.

Thus the capacitance $C = \dfrac{an}{4\pi d}$

If a dielectric other than air is used the specific inductive capacity of this dielectric must be taken into account thus:

$$C = \frac{a K n}{4\pi d} \quad \text{where } K \text{ is the specific inductive capacity.}$$

The formula above gives the capacitance of the condenser in electrostatic units.

To convert to the practical units—microfarads—since $1\mu F. = 9 \times 10^5$ electrostatic units.

The capacitance $= \dfrac{a\,k\,n}{4\pi d \times 9 \times 10^5}$ microfarads.

The energy stored in a condenser is given by

$W = \dfrac{Q^2}{2c}$ where Q is the charge in coulombs and C is the capacitance in farads.

Substituting given values:

$$W = \frac{40 \times 40 \times 10^{-6} \times 10^{-6}}{2 \times 0 \cdot 5 \times 10^{-6}} = \frac{16}{10^4}$$

$$= 0 \cdot 0016$$

Answer. The energy stored in the condenser $= 0 \cdot 0016$ joules.

A condenser is built up of metal foil sheets 10 cms. by 8 cms. spaced at 0·4 millimetres by a dielectric having an S.I.C. of 4. Find the number of sheets required to produce a condenser having a capacitance of 0·025 microfarads.

The capacitance of a parallel plate condenser:

$$C = \frac{a\,K\,n}{4\pi d \times 9 \times 10^5} \text{ microfarads.}$$

$$0 \cdot 025 = \frac{80 \times 4 \times n}{4\pi \times 0 \cdot 04 \times 9 \times 10^5} = \frac{2n}{900\pi}$$

$$\frac{0 \cdot 025 \times 900\pi}{2} = n$$

and $n = \dfrac{0 \cdot 025 \times 900\pi}{2}$

$$= 35 \cdot 325$$

Since there is always one more plate than dielectrics there will be 36 plates.

Answer. The number of plates required will be 36.

The anode of an electrolytic condenser consists of an aluminium cylindrical vessel of 3 in. length

having an internal diameter of 1 in. If the whole of the internal area is in contact with the electrolyte and the forming voltage of 500 volts gives a capacitance of 1·5μF. per square inch, what is the capacitance of the condenser?

Since the capacity of the condenser is proportional to the contact area of the anodic film it will be necessary to find the internal area of the cylindrical vessel, i.e. area of the base, plus area of cylinder.

Area of base of cylinder $= \pi r^2$
$$= 3\cdot14 \times 0\cdot5 \times 0\cdot5 =$$
$$0\cdot785 \text{ sq. in.}$$

Area of cylinder $= \pi dl$
$$= 3\cdot14 \times 1 \times 3 = 9.42$$
$$\text{sq. ins.}$$

Total internal area of cylindrical vessel
$$= 0\cdot785 + 9\cdot42$$
$$= 10\cdot205 \text{ sq. ins.}$$

The capacitance of 1 sq. in. of material is 1·5 μF.

∴ Total Capacitance $= 1\cdot5 \times 10\cdot205$
$$= 15\cdot308 \ \mu F.$$

Answer. The capacitance of the electrolytic condenser will be 15·308 μF.

What materials and methods are employed in the construction of tuning coils for Tuned Radio Frequency receivers covering ranges of 200-550 and 1000-2000 metres? Why?

Tuning coils used in Tuned Radio Frequency or "straight" receivers are usually wound on formers of ebonite, fibre, paxolin or other similar insulating material. The formers are normally circular or hexagonal in cross section and have a diameter of from 1¼ to 2½ inches.

It is not necessary to employ low-loss insulating material since insulator losses at broadcast frequencies are not severe.

Frequently slots or ribs are incorporated in the former

to facilitate spacing of the windings, thus reducing self-capacity losses.

The wire usually used for the winding of medium frequency coils is 20–24 S.W.G. copper, although thinner wire, 30 S.W.G. may be used for reaction windings.

Formerly solid wire was used, but it is now common practice to employ stranded or Litzendraht (Litz.) wire to minimise eddy current and skin effect losses which increase as the frequency rises.

There are two types of tuning coil used in a "straight" receiver, firstly the Radio Frequency Transformer for the R.F. amplifier stages which possesses two windings, an aerial coupling and a grid tuning winding respectively, and secondly the detector stage coil which includes coupling and grid tuning windings, identical with those of the R.F. Transformer and in addition a reaction winding to overcome circuit losses and to increase sensitivity.

To cover the two ranges it is necessary to divide the aerial coupling and grid tuning windings into two sections, one to cover the 200–550 metre range, and a larger section which in conjunction with the smaller winding covers the 1000–2000 meter range. When tuning over the higher frequency range, the low frequency sections of both coupling and grid coils are short-circuited by means of one three-point or two single-make switches. To prevent the short-circuited windings introducing too heavy a loss of energy, medium wave sections are wound at one end of the former, as single layer coils or solenoids, whilst the additional windings to cover the long wave range are wound at the opposite end either as self-supporting honeycomb coils or on slots cut in the former.

The reaction winding is normally placed between the medium and long wave sections to afford reasonable coupling with both.

To facilitate connection the windings are terminated on soldering tags or terminals incorporated in the former.

Some coil manufacturers do not employ tapped coupling coils in which case one single-make switch is sufficient for switching.

Construction and circuit wiring of a typical dual range coil are illustrated in Figs 6 and 7.


M W GRID WINDING

M.W. AERIAL
COUPLING WINDING
REACTION WINDING

L W GRID WINDING

L.W AERIAL
COUPLING WINDING
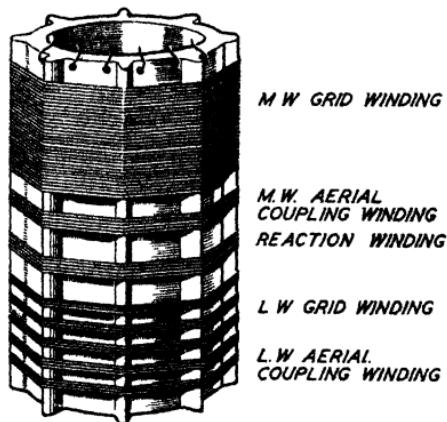
FIG. 6.
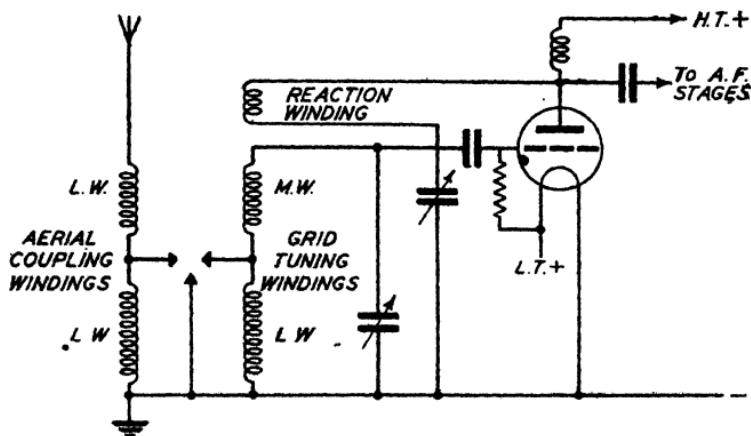
FIG. 7.

What is the difference in operation of high-frequency and low-frequency chokes? Describe the

construction of one of each type and draw sketches illustrating the use of each.

A high-frequency choke is designed to offer a high impedance to radio-frequency current whilst offering a low impedance path to direct current.

This is achieved by winding the choke with many turns of fairly fine wire on a narrow diameter former of high insulating material, and dividing the winding into several pile wound sections to minimise self-capacity. The gauge of the wire used must be sufficiently stout to carry the direct current component without undue heating.

Connection to the H.F. choke is made by means of soldering tags, wire ends or screw terminals.
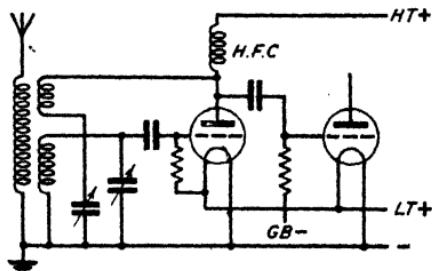

FIG. 8.   FIG. 9.

Fig. 8 illustrates the construction of a typical H.F. choke whilst Fig. 9 shows such a choke used in the H.T. feed of a detector valve to prevent radio-frequency current reaching the audio stages via the H.T. supply.

A low-frequency choke is constructed to offer a high impedance to audio-frequency current whilst permitting the unrestricted passage of direct current.

The choke consists of a laminated iron core on which are wound very many turns of wire.

The core concentrates the magnetic field which produces a considerable increase in the effective inductance of the coil. Again the wire used must be of a gauge sufficiently heavy to carry the required direct current without heating up.

39
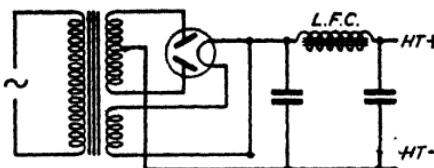
FIG. 10.

The choke is normally fitted with a metal cover to afford a magnetic screen, connection to the winding being made by soldering tags or terminals.

Fig. 10 shows a low-frequency choke used in the smoothing circuit of a high-tension power unit operating from A.C. mains. The choke, in conjunction with the two by-passing condensers, effectively reduces the level of the A.C. component superimposed on the H.T. supply.

Define the terms (a) Coefficient of self-induction. (b) Coefficient of mutual induction.

The co-efficient of mutual induction of an induction coil is 2·5 henrys. A current of 1·2 amperes in the primary is cut in 0·002 secs. Calculate the electromotive force set up in the secondary coil.

(a) The coefficient of self-induction is the total number of lines of force passing through any circuit and due entirely to one C.G.S. unit of current traversing that circuit.

(b) The coefficient of mutual inductance of two coils may be defined as the total magnetic flux which passes through one of the coils when the other is traversed by one C.G.S. unit of current.

Electromotive force induced = inductance × rate of change of current.

Mutual inductance = 2·5 henrys.

$$\text{Rate of change of current} = 1 \cdot 2 \times \frac{1}{0 \cdot 002} \text{ amps. per sec.}$$

$$\therefore \text{Induced voltage} = 2 \cdot 5 \times 1 \cdot 2 \times \frac{1}{0 \cdot 002} = 1500 \text{ volts.}$$

Answer. The electromotive force = 1500 volts.

***Explain the action of a mains transformer and
show how the secondary voltage and current are
deduced from the input voltage and current.
When is it usual to employ air core transformers?***

In its simplest form a mains transformer consists of
a combination of two coils wound on a common core
of soft iron or other suitable material. These coils
are known as the primary and secondary coils or
windings. The primary winding is connected to the
main alternating current source and this varying
current in traversing the primary winding sets up a
varying magnetic field in the core. These magnetic
lines of force cut the turns of the secondary winding
and induce an electro-motive force (e.m.f.) in it.
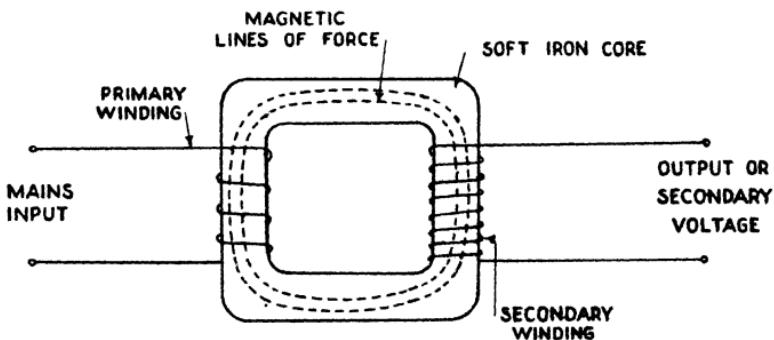
PRINCIPLE OF THE MAINS TRANSFORMER
FIG. 11.

Fig. 11 illustrates this theory. It will be appreciated
that if an e.m.f. is induced in the secondary winding
there will also be an induced secondary current.
Briefly then, a transformer is a device, the action of
which provides a means for transferring variations of
voltage and/or current in one circuit (the primary
circuit) to another circuit (the secondary circuit) by
means of electromagnetic induction.

The ratio of the total voltage induced in the secondary
winding to that applied across the primary depends

upon the ratio of the number of turns between the two windings, i.e. the transformation ratio. For example, if an A.C. supply of 200 volts was applied to the primary winding of a transformer having 100 turns, then, if the secondary winding had 200 turns, the output or secondary voltage would be

Input voltage × transformation ratio

$$= \text{Input voltage} \times \frac{\text{Secondary turns}}{\text{Primary turns}}$$

$$= \frac{200 \times 200}{100} = 400 \text{ volts.}$$

The secondary current varies inversely as the transformation ratio thus:

Secondary current =

$$\text{Primary current} \times \frac{\text{Primary turns}}{\text{Secondary turns}}$$

Air core transformers are usually employed in high-frequency circuits where iron cores would cause serious loss of energy owing to eddy currents being induced in the iron.

Define the terms:
    (*a*) **Step-up transformer.**
    (*b*) **Closed core transformer.**
    (*c*) **Auto-transformer.**
    (*d*) **Step-down transformer.**
Mention three types of transformer used in radio-communication.

(*a*) *Step-up transformer.*
A transformer in which the secondary winding consists of a greater number of turns than the primary winding resulting in a greater secondary voltage than primary voltage and thus a lower secondary current than primary current.

(*b*) *Closed core transformer.*
A transformer in which the iron core forms a complete magnetic circuit without any air gap.

(c) *Auto-transformer.*

A transformer consisting of a single winding, part of which is tapped off for the primary winding, and part for the secondary winding (see also p. 44).

(d) *Step-down Transformer.*

A transformer in which the primary winding consists of more turns than the secondary winding. This results in a lower, secondary voltage than primary voltage and a greater secondary current than primary current.

Three types of transformer used in radio communication are:

(1) Mains or power transformers which are used for transforming voltages in the power supply circuit.

(2) Audio-frequency transformers.

(3) Radio-frequency transformers.

What are " eddy currents "?
How are these currents (a) utilised; (b) minimised?

If a conductor is moved relatively in a magnetic field then currents are induced in accordance with Lenz's law which states that "The current induced in a conductor will flow in such a direction that its effect will be to oppose the originating motion." The currents so induced in any piece of metal such as the armature of a dynamo or motor, the core of a transformer, choke coil, or relay, or any piece of metal which moves in a magnetic field but does not form part of a magnetic circuit, are termed "eddy currents."

(a) Eddy currents, as stated by Lenz, tend to oppose the movement of the conductor or, if the field is varying around a stationary conductor, they oppose the variation of the field. This property is made use of in the manufacture of electrical instruments of the "dead beat" variety. In moving coil instruments the coil is wound on a light metal frame, which, moving in the field of the permanent magnet produces eddy currents,

resulting in a steady, vibrationless movement of the needle.

The same effect is produced in hot wire instruments by arranging for a light sheet of metal to move across the face of a magnet.

(e) Eddy currents are a disadvantage in armature and transformer cores as they represent wasted energy which is radiated as heat and decreases the insulation resistance of the windings. The currents are reduced by using laminated cores which are built up from sheet metal, each layer being insulated from its neighbour by paper or varnish. The layers are arranged in the direction of the magnetic field and are secured by bolts in insulating bushes. Where very high frequencies are used cores are manufactured from iron dust mixed with insulating cement, to separate the particles, the mixture being moulded under high pressure.

Describe the principle of the auto-transformer, What are the advantages and limitations of this type of transformer?

The auto-transformer consists of a single coil with a number of tappings taken from it. Figs. 12 and 13 show a step-down and step-up auto-transformer respectively. In the sketches below the coil has a single tapping, the connections for the primary being the two ends of the coil for a step-down transformer


FIG. 12.   FIG. 13.

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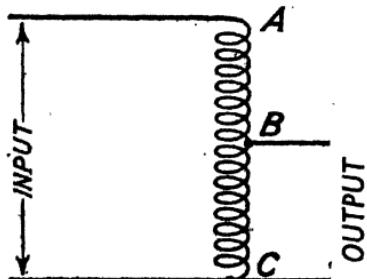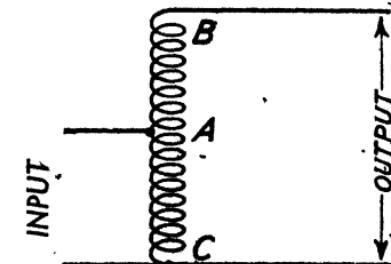
and the tapping and one coil end for a step-up transformer, while the secondary connections would be the tapping and one coil end and the coil ends respectively.

In Fig. 12 the number of turns between B and C is two-thirds of the total turns.

Suppose that the secondary delivers a current of 6 amps. Then, since the ampere turns of the primary winding must equal the ampere turns of the secondary winding, the current in the primary will be $6 \times \frac{2}{3} = 4$ amperes.

Thus we have a current of 6 amps. from C to B and a current of 4 amps flowing in opposition from A to C, so that the actual current in CB is 2 amps.

The relationship between input and output voltages and currents and the turns ratio apply to the auto-transformer in the same way as to a normal two-coil transformer, i.e. the voltages are directly proportional and the currents inversely proportional to the turns ratio.

Advantages of the Auto-transformer.

The advantage of an auto-transformer over a normal two-coil transformer is that a considerable saving can be effected in the amount of copper used and a reduction in copper losses. This advantage is highest when the transformer ratio reaches unity.

Disadvantage of the Auto-transformer.

The disadvantage of using an auto-transformer is the danger of applying the primary voltage to the secondary leads if a disconnection occurs in the common winding of a step-down auto-transformer. This is also the reason for limiting the transformation ratio of this type of transformer.

Explain how the efficiency of a transformer may be measured. A 20 K.V.A. 2200/200 volt 50 cycles single-phase transformer gave the following test results:

Open-circuit test 2200 volts applied to primary—power 220 watts.

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Short-circuit test-power required to circulate full load current in short-circuited secondary, 240 watts.

Calculate the efficiency at full load with unity power factor if the iron losses equal 220 watts and the full load copper losses are 240 watts.

The direct method of measuring the efficiency of a transformer is to measure the power input and the power output by means of wattmeters, and then calculate the efficiency with the following formula:

$$\text{Efficiency} = \frac{\text{Output}}{\text{Input}} \times 100 \text{ per cent.}$$

The efficiency may, however, be estimated as follows:

$$\text{Efficiency} = \frac{\text{Output}}{\text{Input}} = \frac{\text{Output}}{\text{Output} + \text{losses}}$$

The losses include the iron and copper losses and these may be measured by means of the open-circuit and short-circuit tests respectively. In the above question the output = 20 K.V.A. = 20,000 watts. The iron and copper losses equal 220 and 240 watts respectively, therefore:

$$\text{Efficiency} = \frac{\text{Output}}{\text{Output} + \text{losses}} = \frac{20,000}{20,000 + 220 + 240}$$

$$= \frac{20,000}{20,460} \times 100 \text{ per cent.}$$

$$= 97\cdot74 \text{ per cent.}$$

Ans. The efficiency of the transformer is 97·74 per cent.

A transformer takes 0·5 ampere when its primary is connected to a 400-volt supply, the secondary being on open circuit. The power absorbed is 25 watts. Calculate the iron loss current and the magnetising current.

The power absorbed $P = E \times I \times \text{Cos } \theta$

$$25 = 400 \times 0\cdot5 \times \text{Cos } \theta$$

$$\frac{25}{400 \times 0\cdot5} = \text{Cos } \theta$$

$$\therefore \text{Cos } \theta \quad = 0 \cdot 116$$
$$\text{and } \theta \quad = 83° \, 30'$$

The iron loss current $= I \text{ Cos } \theta = 0 \cdot 5 \times 0 \cdot 1136 =$
0·0566 ampere.

The magnetising current $= I \sin \theta = 0 \cdot 5 \times 0 \cdot 9936$
0·4968 amperes.

Ans. The iron loss current is 0·0566 ampere, and the magnetising current is 0·4968 ampere.

CHAPTER III

VALVES

Sketch and describe the construction of the two-electrode thermionic valve. If the valve was worked with the filament temperature above that specified what effects would result?

The two electrode thermionic valve consists essentially of an evacuated glass envelope containing a tungsten- or oxide-coated filament wire and an anode collector plate. The latter is often cylindrical in shape and completely surrounds the filament wire. Both the filament and the anode are supported by wires held rigidly in the pinch of the glass envelope. These wires act as the filament and anode leads. A bakelite cap containing the external contact pins is rigidly cemented to the base of the glass envelope, and the filament and anode leads are soldered to these pins, Fig. 14 shows the general construction of the valve.


FIG. 14.

48
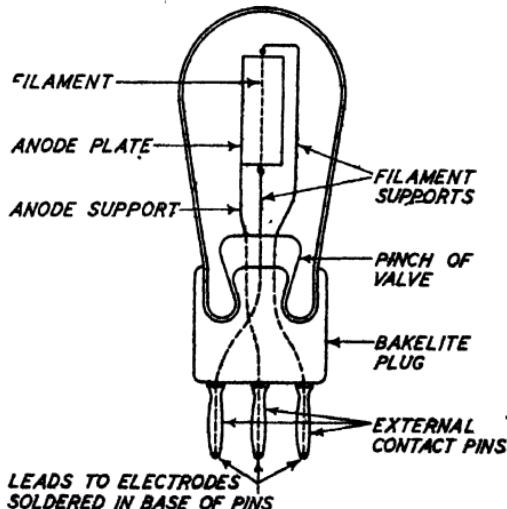
If the valve is worked with the temperature of the filament raised above that specified, an increased electron emission will occur resulting in a larger anode current than that specified, this may well prove undesirable. This excessive emission would, of course, reduce the useful life of the valve due to the fact that the filament would lose its emissitivity at a greater rate.

Does the electronic current flowing in the anode circuit of a diode valve obey Ohm's Law? That is, does the current vary directly as the applied anode voltage.

The electronic current flowing from the filament to the anode of a valve, although a function of the applied anode voltage, does not vary directly as the applied voltage. In other words, the valve, as a conductor, does not obey Ohm's Law.


FIG. 15.

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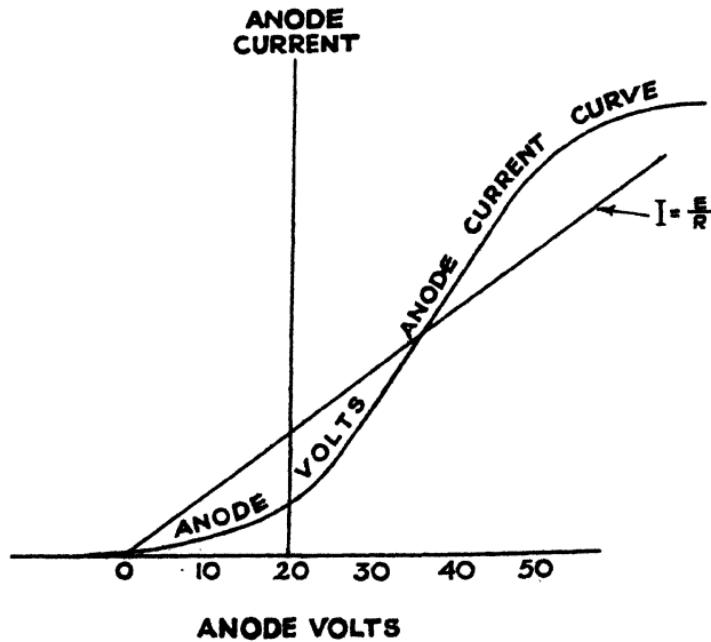
Fig. 15 shows a typical anode voltage/anode current curve of a diode valve. This curve is obtained by connecting a valve in the circuit shown in Fig. 16 and noting the current flowing, with various values of anode voltage.
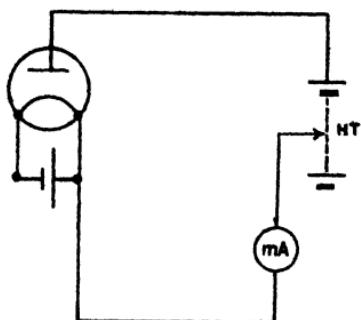
It will be observed that at the beginning the increase in current is very small and rises very slowly per volt increase, but later the anode current curve rises steeply so that there is a comparatively large anode current increase per anode volt increase. Finally "Saturation point" is reached. That is when any further increase in applied anode voltage fails to increase the anode current flow. The straight line indicates the Ohm's Law, $I = E/R$ curve.

FIG. 16.

Explain briefly the construction of a triode valve, and by means of a sketch show the relative position of the electrodes. Draw the symbol of the triode valve. What is the function of the grid electrode?

Fig. 17 shows the relative positions of the electrodes of the triode valve. It consists of three electrodes known as the filament, or cathode, the grid and the anode. (In Fig. 17 a portion of the circular anode has been cut away to show the electrode disposition clearly.)

The filament wire may be either tungsten or oxide coated (see p. 52), cut to given length and welded to two nickel filament supporting rods about 0·4 mm. thick. The grid wire is wound on and welded to two more nickel rods and forms a wire meshwork which completely surrounds the filament wire. The anode

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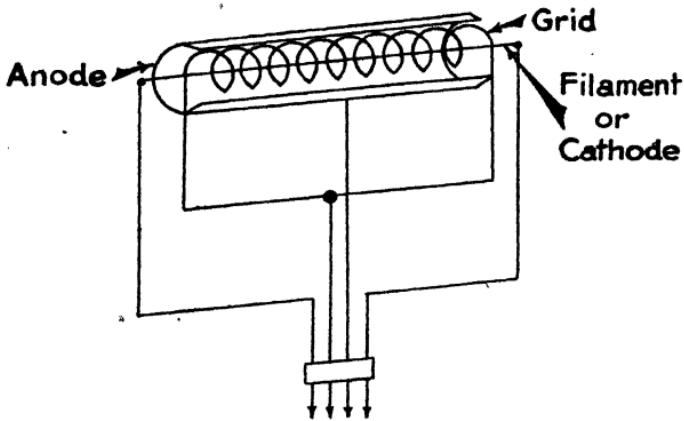
FIG. 17.

may be either circular or rectangular in shape and surrounds the filament and grid electrodes. The electrode assembly is then mounted in a glass tube and sealed, after which all traces of occluded gas and air are removed from the tube by means of a pumping process. Finally the glass envelope is fitted with a bakelite base and its electrode connections soldered to the contact pins in a similar manner to the diode Fig. 14.

The symbol for a triode valve is shown in Fig. 18. When a wire mesh (grid) having openings through which electrons pass is placed between the filament and the anode, it exerts a large "controlling force" (by virtue of its being nearer the cathode than is the anode) on the flow of electrons from the filament to the anode. When the grid is connected to a voltage source, the electrons emitted from the filament or cathode, are attracted if the grid is positive with respect to the filament or cathode and repelled if it is negative.


FIG. 18.

51
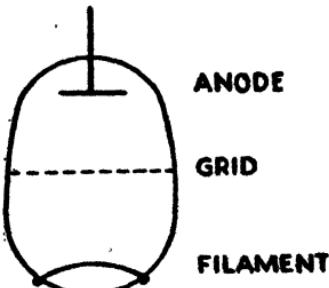
The electrons reaching the anode do so via the grid mesh, being drawn through the grid mesh by the positive potential of the anode. The resulting anode current is controlled by the potential of the grid with respect to the filament or cathode.

The effect of a large positive anode voltage in drawing the electrons to the anode can be reduced by a relatively small negative voltage applied to the grid. Voltage variations of the grid produce corresponding variations of the anode current. Thus a small change in voltage on the grid affects the anode current to the same extent as a larger change in anode voltage. The ratio of these voltage changes is called the amplification of the valve.

Explain the action of the cathode electrode of a valve. Name three types of material used for cathodes, which material would you use for the cathode of a high-power valve?

The ability of a hot metal to emit electrons is the basis of the thermionic valve.

The hot metal is the filament or cathode, and it is made of a material which, raised to a temperature less than its melting point, gives adequate electron emission for the purpose for which the valve is required.

Three materials used for cathodes are:

  (1) Pure Tungsten operating at approximately 2500° absolute.
  (2) Thoriated Tungsten, operating at approximately 1850° absolute.
  (3) Certain oxide-coated metals operating at approximately 1110° absolute.

For (3) metals such as platinum, nickel, tungsten or molybdenum are used as the core and a mixture of Barium and Strontium oxides is coated on the surface.

Cathodes made of tungsten are used extensively for high-power valves because of their durable qualities, and retentivity of emissive properties.

***What do you understand by an indirectly heated
cathode? Illustrate your answer with a suitable
sketch. What advantage is claimed by its use?***

An indirectly heated cathode is a cathode in a thermi-
onic valve which is not heated directly by the passage
of a current through it, but by radiation from a heater
close to it which is connected to the supply. Fig. 19
shows the arrangement. Valves operated direct from
the supply mains are usually of this type to reduce
any variations in the emission of electrons from the
cathode which might otherwise be caused by variations
in the heating current flowing directly through the
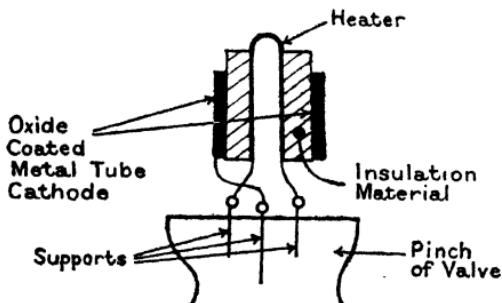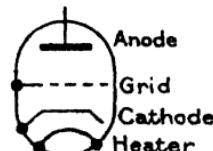

FIG. 19.   FIG. 20.

cathode. Fig. 20 shows the symbol for an indirectly
heated triode valve.

Due, however, to the impossibility of obtaining the
requisite temperatures by indirect heating for tungsten
and thoriated tungsten, oxide-coated emitters are
always employed for indirectly heated cathodes.

***State briefly the meaning of the following terms:
(a) Space Charge; (b) Saturation Point; (c)
Characteristic Curve.***

(a) *Space Charge.*

At any instant during the normal working of a
valve the space between the filament and the anode
becomes filled with a cloud of negative electrons moving
from filament to anode. The electrons nearest the
anode at any moment are not only being attracted by

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the positive anode but are also being repelled towards it by the immediately following electrons. The electrons which are farther away from the ₊anode, however, have not only fewer electrons behind them to push them towards the anode, but have electrons in front of them tending to push them back towards the filament. This phenomenon is known as *the space charge,* and its effect is to choke back the stream of electrons from the filament to anode.

Saturation Point.

Saturation point is reached when all the electrons emitted by the filament are collected by the anode.

With this condition existing, any further increase of anode potential fails to increase the anode current flowing.

Characteristic Curve.

A plotted curve which clearly illustrates the characteristics of the valve. In the case of the diode valve it is a curve showing the anode current flowing with various anode voltages applied. Figs. 15, 23 and 44 show a typical characteristic curve of (*a*) a diode; (*b*) a triode and (*c*) a screened-grid valve respectively.

Explain with the aid of a graph the meaning of the term " mutual conductance."

Mutual conductance is the term used to denote the rate of change of anode current with change of grid voltage, the *anode voltage remaining constant.* It is the gradient or slope of the mutual-characteristic, expressed in milliamperes per volt, and designated by the symbol *gm*. From the graph Fig. 21 it will be noticed that a change of grid potential from $-2V$ to $+2V$ gives a *change* in anode current of 0·4 mA. to 1·0 mA. The ratio of these two differences gives the mutual conductance of the valve, i.e.

$$gm = \frac{\text{a change in anode current}}{\text{a change in grid voltage}}$$

$$= \frac{d\,Ia}{d\,Vg}$$

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Milliamperes

Anode Voltage +5OV.

Grid Potential. Vg
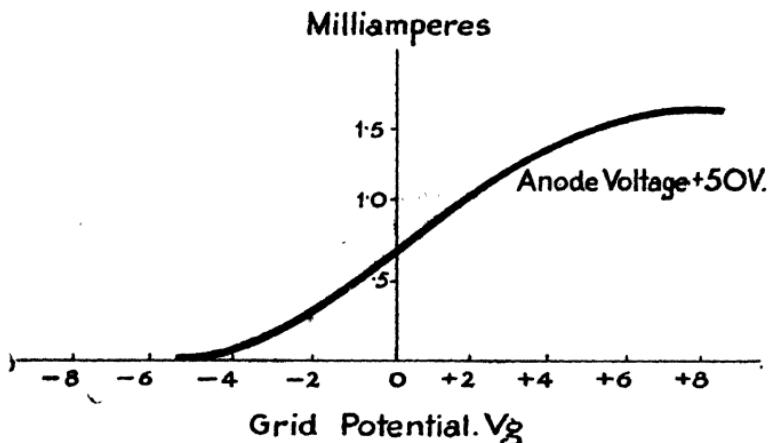
FIG. 21.

Substituting values taken from curve.

$$gm = \frac{1 \cdot 0 - 0 \cdot 4}{2 + 2} = \frac{0 \cdot 6}{4} = 0 \cdot 15 \text{ mA per volt.}$$

This simply means that a change of potential on the grid of one volt will bring about a *change* of anode current equalling 0·15 mA. This value of mutual conductance only applies to that part of the curve where the values were taken, but if the slope of the curve is constant, the mutual conductance will be constant. Therefore the mutual conductance is always measured about the middle of the curve.

Sketch a circuit for checking the characteristics of a triode valve. Describe any precautions necessary.

Draw a typical example of an anode current-grid voltage curve of a triode valve.

The potentiometer P_1 is connected across the centre tapped grid-bias battery to enable either negative or positive potentials to be applied to the grid of the valve. The grid voltage being measured by the high resistance voltmeter V_1. The anode potential is varied

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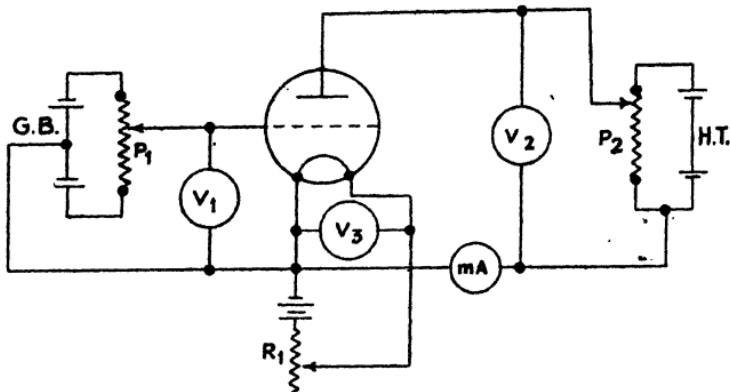
FIG. 22.

by means of the potentiometer P_2 connected across
the H.T. battery. The anode voltage is measured by
the high-resistance voltmeter V_2 and the anode current
by means of the milliammeter. When the correct
filament voltage read on the voltmeter V_3 has been
obtained by means of the rheostat R_1 the anode voltage
is kept constant while the grid voltage is changed in
small steps from *negative* to a positive value with
respect to the filament. With each change of grid-
bias valve the anode current is recorded. The anode
voltage is then changed and the procedure repeated.
The anode current readings are then plotted against
grid-voltage readings for the corresponding anode
voltages. A typical anode current grid-voltage curve
of a triode valve is shown in Fig. 21.

*The table on page 57 gives the current flowing in
the anode circuit of a triode valve with selected anode
voltages and various grid voltages applied. From
the table plot a " family " of mutual characteristic
curves and from these plot the dynamic character-
istic curve of the valve with a load resistance of
20,000 ohms. Explain how you obtained this
curve; with its aid explain how voltage amplifica-
tion is achieved.*

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TABLE I

| GRID BIAS	FIXED ANODE · VOLTS			
	130 VOLTS	120 VOLTS	110 VOLTS	100 VOLTS
−4 Volts	Ia 0 mA	Ia 0 mA	Ia 0 mA	Ia —
−3 . "	0·5 ·	0 ·	0 "	—
−2 ·	1·0 ·	0·5 ·	0 "	—
−1 . "	1·5 ·	1·0 "	0·5 ·	0
0 ·	2·0 ·	1·5 ·	1·0 ·	0·5
1 ·	2·5 ·	2·0 ·	1·5 ·	1·0
2 ·	3·0 ·	2·5 ·	2·0 ·	1·5
3 ·		3·0 ·	2·5 ·	2·0

FIG. 23.

Fig. 23 shows the family of mutual characteristic curves together with the dynamic characteristic curve. The dynamic characteristic curve is obtained in the following manner: Taking the highest anode voltage curve (130 volts), it will be seen that when the grid potential is −4 no anode current flows, hence, there will be no potential drop across the 20,000-ohm load

resistance, i.e. the anode and H.T. potentials are the same. This condition is represented by point A. Next vary the grid potential until the anode current flowing is 0·5 mA., then the potential drop across the load resistance $= \dfrac{0·5}{1000} \times 20,000 = 10$ volts. Thus the next point is fixed on the 120 volt characteristic where the anode current flowing is 0·5 mA., corresponding to $-1·9$ grid volts. Next, when 1 mA. flows the voltage drop across the anode load will be $\dfrac{1}{1000} \times 20,000 = 20$ volts. Thus point C is determined on the 110 volt characteristic with an anode current of 1 mA. The last point is determined in a similar manner. The dynamic characteristic is obtained by connecting these points together.

By inspection of Fig. 23 it will be observed that to produce an anode current of 0·5 mA., a change of grid potential of 1·9 volts is necessary, e.g. from 0 to 1·9. This will produce a voltage variation of 10 volts across R. Thus a change in anode current causes a variation in voltage across the anode load resistance which will be a magnified version of the change in grid voltage, or in other words (there is amplification and the valve acts as an amplifier) voltage amplification has been achieved.

A triode valve has a characteristic given by
$$Ip = 0·002\frac{1}{1}(Ep + 10\ Eg)^2$$
   where Ip is the plate current in milliamps
   ,,   Ep ,, ,,   ,, voltage
   and   Eg ,, ,,   ,, grid voltage
Plot the characteristic curve for an anode voltage of 160 between values of Eg = +4 and Eg = —16 volts. What is the mutual conductance of the valve at zero grid potential with the above anode voltage.

Table 2 shows the values of Ip for values of Eg between -16 and $+4$ volts, and the curve, Fig. 24 is drawn from these values.

TABLE 2

Eg	10Eg	$(Ep + 10Eg)^2$	$Ip = 0.002 (Ep + 10Eg)^2$
— 16	—160	0	0 mAs
— 14	—140	0.4×10^3	0.8 ,,
— 12	—120	1.6×10^3	3.2 ,,
— 10	—100	3.6×10^3	7.2 ,,
— 8	— 80	6.4×10^3	12.8 ,,
— 6	— 60	10×10^3	20 ,,
— 4	— 40	14.4×10^3	28.8 ,,
— 2	— 20	19.6×10^3	39.2 ,,
0	0	25.6×10^3	51.2 ,,
2	20	32.4×10^3	64.8 ,,
4	40	40×10^3	80 ,,

THE MUTUAL CHARACTERISTIC CURVES.
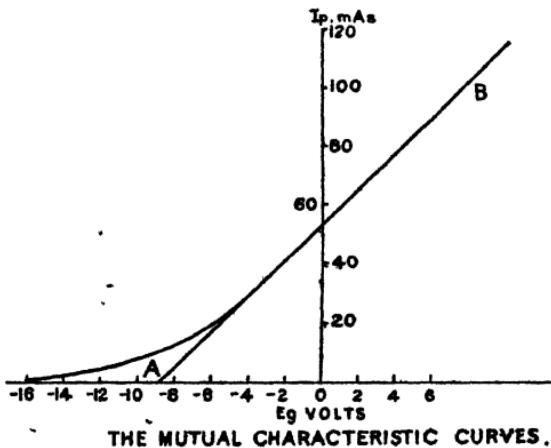
FIG. 24.

The mutual conductance of a valve is equal to
$$\frac{\text{change in anode current}}{\text{change in 1 volt of grid bias}} \text{ or } \frac{\delta Id}{\delta Eg}$$

Taking the straight part of the mutual characteristics between —2 and +2 we have

At + 2 volts, anode current = 64.8   (from table)

At — 2 volts, anode current = 39.2

difference   25.6

A change of 4 grid volts produces a current change of 25.6 milliamps.

$$\text{Mutual Conductance} = \frac{25 \cdot 6}{4} = 6 \cdot 4 \text{ mA.}$$

Ans. The mutual conductance of the valve is 6·4.

What is the difference between the static and dynamic characteristic curves of a valve? Which type of curve is the most important? What do you understand by a load resistance? Draw a circuit incorporating a load resistance.

The static characteristic of a valve shows the relation between the steady voltage applied to the grid, and the anode current, when the anode voltage is kept constant, or it may, show the relation between anode voltage and anode current when the grid voltage is
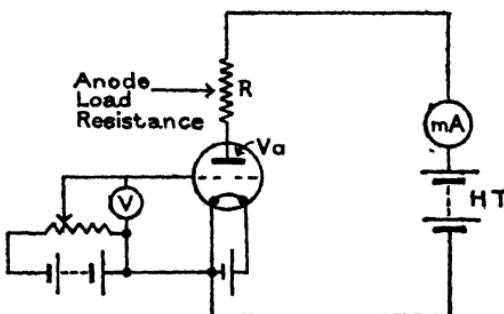
FIG 25.

kept constant. A dynamic characteristic, however, shows the performance of a valve under working conditions when alternating voltages are being applied.

The dynamic characteristic curves are by far the most important as they give a true picture of the valve under working-conditions. A load resistance is a high-value resistor (usually several thousand ohms) placed in series with the anode of the valve as shown in Fig. 25. When an anode current flows, there will be a potential drop across the load resistance equal to $I_a R$ thus the anode voltage V_a will be less than the H.T. voltage (V), i.e. $Va = V - I_a R$.

What is the object of a load line? Plot the anode characteristics from the following values taken with a triode. If an anode load resistance of 12,500 ohms is connected in the circuit, and the battery voltage is constant at 50 volts, find the anode current, and the voltage across the load resistance from the load line at the given values of grid voltage Vg.

Grid Potential Vg	o	—1	—2	—3
Anode Current mA	2·68	2·35	2·0	16·5
Voltage Across R	33·5	29·3	25	20·6

MEASUREMENTS FROM THE ANODE LOAD LINE.
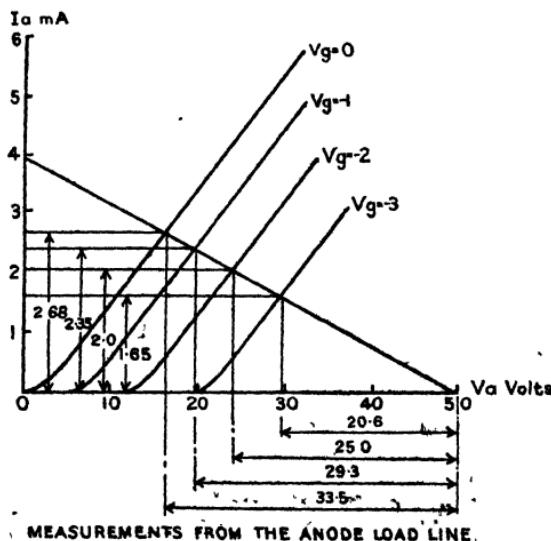
Fig. 26.

The load line is used to determine the dynamic characteristic from the anode current/anode voltage characteristics. It shows the changes in anode current and anode voltage, for a change in grid voltage with a given load resistance. Fig. 26 clearly shows the required anode characteristic curves and the load line with an anode load resistance of 12,500 ohms.

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The anode current flowing and the voltage across the load resistance with the stated values of Vg are clearly shown.

Define briefly class A, B and C amplification.

Class A amplification.

Amplification in which the amplifying valve is so operated that the wave-form of the output is as nearly as possible the same as that of the input.

Class B amplification.

A method of amplification in which two separate valves, or two valves in one envelope, are connected in push-pull and so biased that each valve deals with alternate half cycles of the applied alternating voltage. The change in anode current supplied to the valve can, therefore, be kept less than with class A amplification, with corresponding saving in high-tension supply. It is largely used in battery-operated receivers for this reason.

Class C amplification.

A highly efficient system of power amplification used largely in tuned radio-frequency power amplifiers where the output need not be proportional to the input. The amplifying valve is heavily biased so that when a signal is applied the anode current flows in pulses for less than half a cycle.

Describe how a triode valve acts as a class A amplifier. Show clearly which part of the mutual characteristics curve is used.

A triode valve when used as a class A amplifier is required to produce in the output circuit a current which has a wave-form similar to that of the alternating voltage applied to the grid circuit. Referring to Fig. 27 the portion of the curve between X and Z is approximately straight; and if the grid bias is so adjusted that the valve operates about the midpoint Y and on

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ANODE
CURRENT

mA

Z

Y

Ia

Time

X

−   0   +

GRID VOLTS

Grid bias

Incoming
signal
impressed on
grid voltage

Time
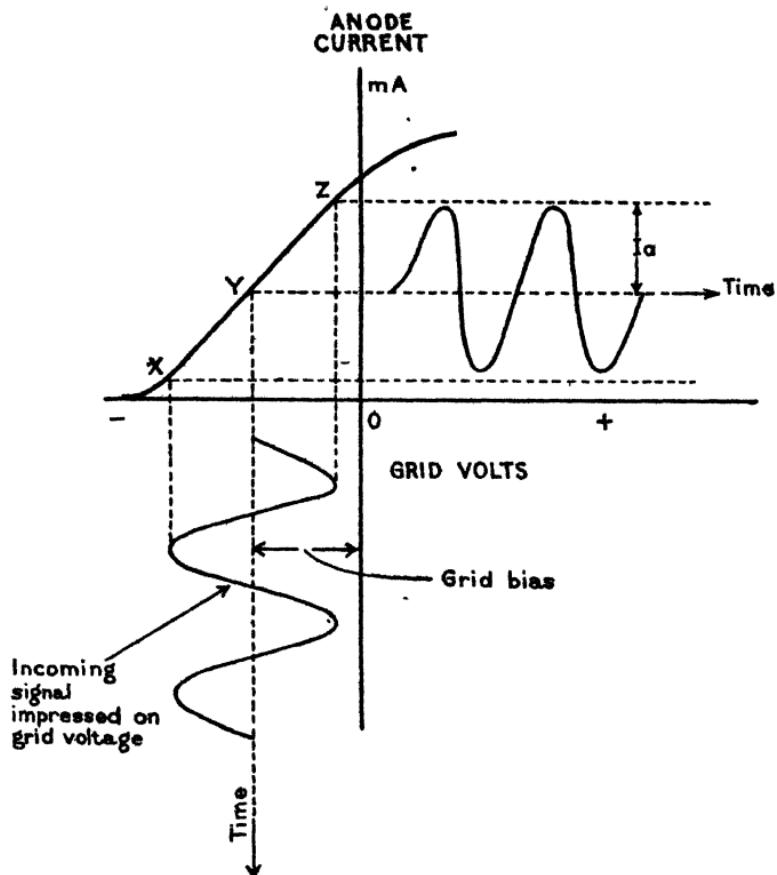
FIG. 27.

this is impressed the incoming signal (alternating voltage) to vary the total grid voltage between the limits of X and Z, the voltage across the anode load will vary in like manner. Thus the wave-form of the anode current resembles the applied alternating grid voltage.

State briefly the principle of the Class B audio amplifier.

In this method the valve is operated at "cut off"

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Anode
Current

Operating
Point

Grid
Volts
←

OPERATION *of a* VALVE
as a CLASS B AMPLIFIER
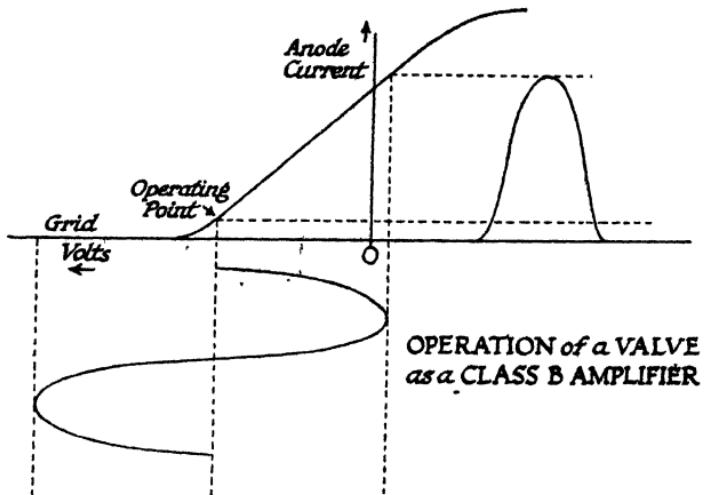
FIG. 28.

on the curve as shown in Fig. 28, from which it will be evident that the negative half-cycle is almost completely suppressed. If this method is used for RF amplification this fact is unimportant, as the inherent Q of the tuned circuit will restore the other half-cycle and remove the harmonics, but for AF amplification this method as it stands is impossible. If, however, two valves are used in push-pull then each valve will supply the missing half-wave of the other, and a normal sine wave will result in the output.

What do you understand by push-pull amplification? What are the advantages claimed by this form of amplification?

· Fig. 29 indicates the push-pull method of amplification. Two similar valves are used. The grids of the two valves are connected to opposite ends of the secondary of the input transformer, thus the grids are fed with equal voltages but of opposite sense (i.e. 180° out of phase). Each valve therefore handles half the input. The two anode circuits are connected to

64
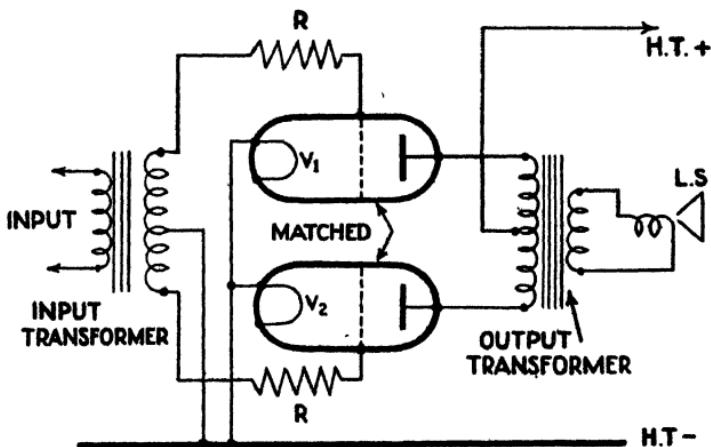
Fig 29.

the opposite ends of the output transformer so that the anode currents are 180° out of phase. The voltages developed across each half of the output transformer are additive. With push-pull amplification distortion is kept to a minimum since the output currents are 180° out of phase. Thus if distortion does occur in the valves, the effects cancel out in the output transformer, producing an undistorted resultant wave.

Show how to measure the amplification factor of a triode valve by means of a simple A.C. Bridge. State any necessary precautions.

Fig. 30 shows a simple schematic diagram of an A.C. bridge capable of measuring the amplification factor of a triode valve. Tone is supplied from an oscillator and heard in the headphones.

C_1 and R_1 are then adjusted until a minimum of sound is heard in the headphones. When this condition is obtained the amplification factor of the valve is given by

$$\text{Amplification Factor } \mu = \frac{R_2}{R_1}$$
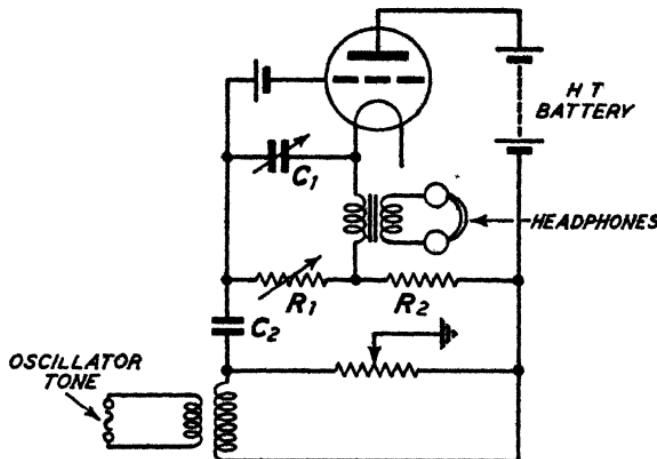
Fig. 30.

If necessary the headphones can be preceded by a suitable amplifier.

The A.C. Tone Voltage should be as small as practicable. The adjustable earth connection on the bridge eliminates the unbalancing effects of capacity to earth.

Give three schematic circuits of single valve amplifiers using different anode load impedances and explain briefly how they differ.

Fig. 31 shows a schematic circuit diagram of a resistance-capacity valve amplifier. The amplified alternating voltage developed across the resistance R is extended to the succeeding stage via the condenser
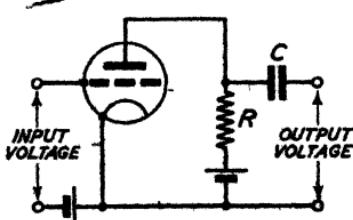
Fig. 31.
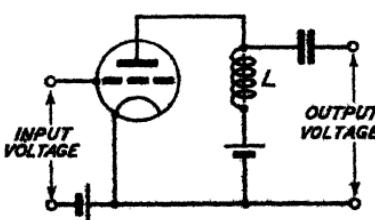
Fig. 32.

C which also prevents the D.C. battery potential from being present at the output terminals.

Fig. 32 represents a choke-capacity arrangement, the choke *L* virtually replacing the resistance *R* in Fig. 31. This system has the disadvantage that the amplified volts across *L* will vary with frequency, since the impedance of the choke (neglecting any resistance) is given by $2\pi fL$.
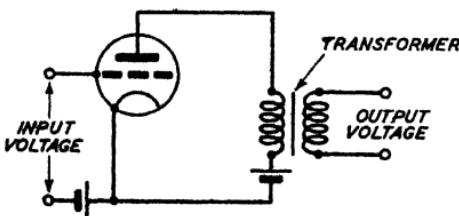
FIG. 33.

The primary of the output transformer represents the anode load impedance in the arrangement shown in Fig. 33. The output voltage will also be proportional to the turns ratio of the transformer. Similarly to the choke-capacity arrangement the anode load impedance will vary with frequency and hence the output voltage will also vary with frequency.

What is an oscillatory circuit? Name two essential properties of an oscillatory circuit, and say why resistance is an undesirable property. What would be the effect of (a) increasing the capacitance, and (b) increasing the inductance of the oscillatory circuit?

A circuit in which an oscillatory current will flow is called an oscillatory circuit. Such a circuit must possess two essential properties, namely capacitance and inductance. Fig. 34 shows a simple oscillatory circuit. Resistance is an undesirable property in an oscillatory circuit because it absorbs the energy which produces the oscillation. If therefore resistance exists the oscillation will be damped. Resistance is kept to a

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CAPACITY · INDUCTANCE
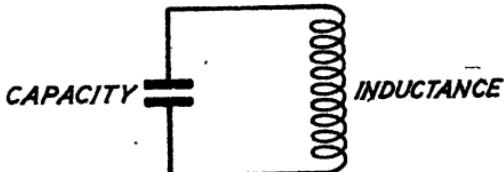
FIG. 34.

minimum in this type of circuit by using a large diameter
conductor and restricting its length as much as possible
The value of the capacitance and inductance determines
the natural frequency of oscillation of the circuit.
The formula connecting frequency, inductance and
capacitance is $f_r = \dfrac{1}{2\pi\sqrt{LC}}$

where f_r is the resonant frequency in c.p.s.

C is the capacitance in farads.

L is the inductance in henries.

The frequency of oscillation will therefore be de-
creased if the capacitance or inductance of the oscil-
latory circuit is increased.

***A condenser is connected to a battery and charged
for a few seconds, after which the battery is replaced
by an inductance coil of "neg-
ligible" resistance. State with
the aid of diagrams the electri-
cal phenomenon which takes
place between the coil and
condenser.***
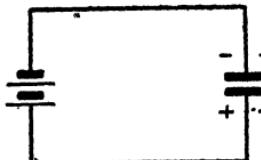
(a)
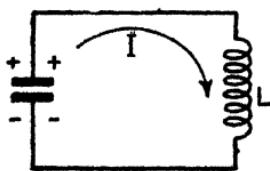
(b)

FIG. 35.

Fig. 35 (a) shows the condenser
being charged by the battery.
When the battery is replaced by
an inductance coil L current flows
from the positive plate of con-
denser to the negative plate via
inductance L. When the current
is a maximum in the coil the
energy stored in it is equal to

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$\dfrac{I^2L}{2}$ and this is equal to the energy previously stored in the condenser, $\dfrac{CV^2}{2}$. At this stage the energy in the condenser is zero. Fig. 35 (b). The current passes through the coil to the negative plate of the condenser with the result that the magnetic field in the coil commences to collapse. The previous negative plate is now charged positive Fig. 36 (a).

The collapsing magnetic field tends to prolong itself by opposing the cause of its collapse (Lenz's

(a)

(b)

Fig. 36.

Law). When it has completely disappeared the condenser is again fully charged but with reversed polarity, and current commences to flow again through the coil (this time in the reverse direction) (Fig. 36b).

The energy in the coil will become a maximum as previously. The condenser will lose its energy and then be charged once again after the current has passed through the coil. The condenser then receives its original polarity. One complete cycle or oscillation has now taken place, and the current commences to make its second oscillation. The oscillations would continue indefinitely if there were no resistance present in the circuit, but as this is always present the amplitude of each succeeding oscillation will become smaller until the oscillation fades out.

How could oscillations in a circuit comprising inductance, capacitance and resistance be maintained by the use of a triode valve?

·A free oscillation would continue indefinitely if -there were no loss in energy and thus no decrease in the amplitude of the wave. Every circuit possesses resistance and therefore loss of energy will occur in
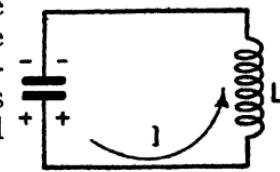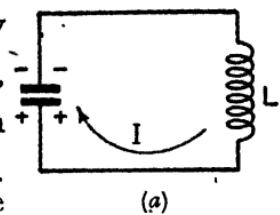
the form of heat. If, however, it could be arranged to supply energy back into the oscillatory circuit at the same rate as it is is expended, the oscillation would be maintained indefinitely. This can be achieved by inductive feed-back coupling with the aid of a triode valve, connected to the oscillatory circuit as shown in Fig. 37.

BY PASS CONDENSER
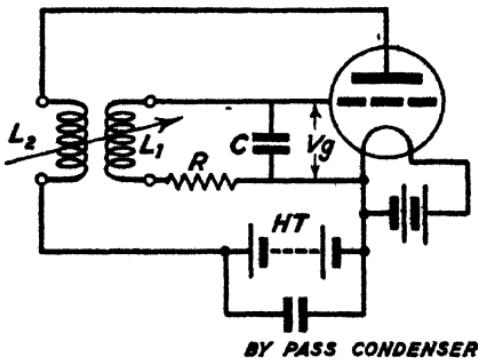
FIG. 37.

The oscillatory circuit (L_1 C and R) is connected between the filament and grid of the valve. The oscillatory grid voltage, Vg causes a current of the same frequency to flow through the valve and the coil L_2. The current flowing through L_2 induces a voltage and current into the oscillatory circuit. Energy is thus introduced into the oscillatory circuit. By suitable adjustment of L_1 and L_2 it can be arranged that the energy introduced into the oscillatory circuit is equal to the energy dissipated in that circuit. As a result of this zero loss, the amplitude of the oscillatory wave is maintained and the oscillation can continue as long as required.

What do you understand by the term anode bend rectifier? State the two methods of anode bend rectification and illustrate each. Which method is preferable?

An anode bend rectifier is a device used for detecting

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wireless signals which makes use of the rectifying properties of the anode to filament path of a valve. It is so named because it employs the bend in the characteristic curve showing the relation between anode current and grid voltage.

The two methods of anode bend rectification are known as the lower anode bend and the upper anode bend methods of rectification. Both methods are rendered possible by the non-linear mutual characteristic curve of the triode valve (Figs. 38 and 39). Operation takes place on the lower bend of the mutual characteristic curve in the first instance and on the upper bend in the second instance.
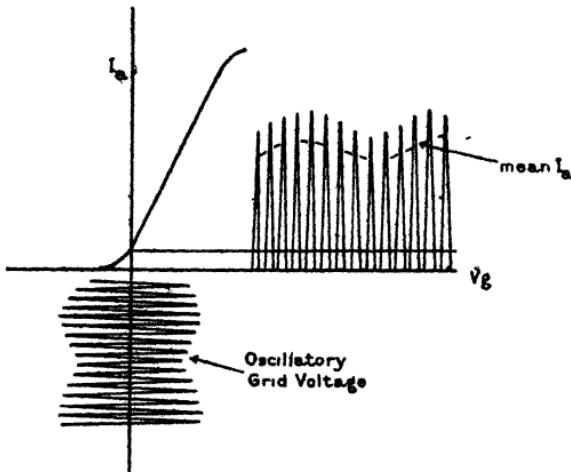
FIG. 38

Fig. 38 illustrates the lower bend method of rectification. Radio frequency oscillations applied between the grid and filament will produce asymmetrical variations of current in the anode circuit since the current increases more during the positive half cycles of oscillatory grid voltage than it decreases during the negative half-cycles.

Fig. 39 illustrates the upper bend method of rectification and from this it can be seen that the anode current

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decreases more during the negative half-cycles of oscillatory grid voltage than it increases during the positive half cycles.
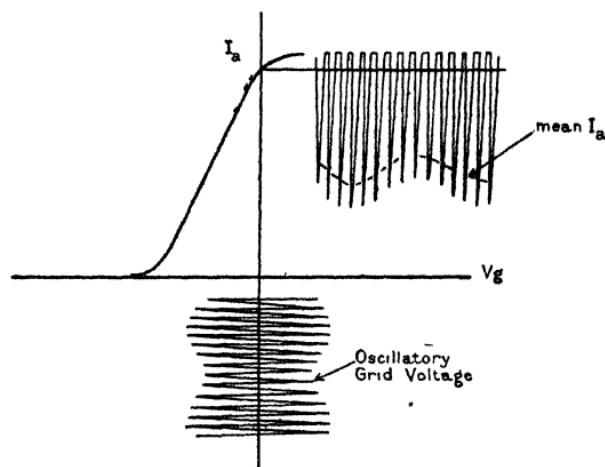
FIG 39

Lower bend rectification is preferable because with upper bend rectification more current is taken from the high-tension battery. Another advantage of lower bend anode rectification is that the normal steady value of grid potential is negative with respect to the filament and therefore no grid current flows. If grid current flows then a certain amount of energy is absorbed from the input circuit, thereby increasing its damping.

What do you understand by cumulative grid rectification? Describe the operation of a cumulative grid rectifier, explaining the action of the grid leak.

Cumulative grid rectification is the term applied to a method of rectifying radio-frequency signals by means of a triode valve and a combination of condenser and resistance (grid leak) connected in the grid circuit.

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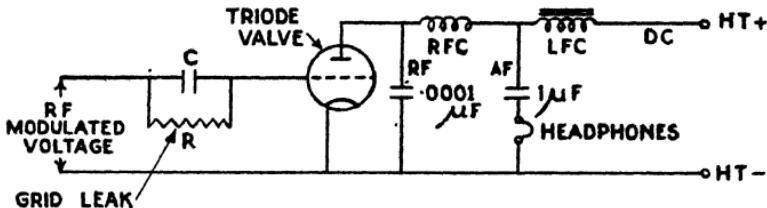
FIG. 40.

Fig. 40 shows one circuit arrangement for cumulative grid rectification.

The action of the leaky grid detector may be best understood if it is considered to comprise a diode detector followed by a triode amplifier.

For rectification the triode grid functions as the anode of a diode. If a radio frequency wave is applied between the grid and filament, as shown in the diagram, the grid will be alternately positive and negative with respect to the filament during succeeding half-cycles. When the grid is positive, electrons will be attracted from the filament (i.e. grid current will flow) and the plate of condenser C connected to the grid will be negatively charged. During negative half-cycles, no grid current will flow thus there will be no increase in the negative grid potential, in fact some of the negative charge will leak away via resistance R. The negative charge on the grid will be increased during each positive half-cycle until the potential developed between grid and filament is equal to the peak R/F voltage. If the applied R/F wave is modulated at an audio-frequency, the negative charge produced on the grid during successive positive half-cycles will vary and if the value of R is chosen to permit the correct leakage during negative half-cycles, the potential across R will follow the modulation envelope of the R/F wave. If the grid leak R is omitted, the grid potential assumes a value equal to the peak of the R/F wave and since grid current ceases to flow, rectification is prevented.

The varying potential across R is applied across the grid and filament of the valve considered as a class

F   73

A amplifier working on the straight portion of its characteristic, the receipt of a signal tending to decrease the mean anode current. Both A/F and R/F components of the varying grid potential are amplified and reproduced in the anode circuit, the latter being by-passed by the ·001 condenser.

The grid rectifier cannot handle an incoming signal of large amplitude for if the grid swing is too great, the working point reaches the curved part of the mutual characteristic where lower anode bend rectification occurs, distortion being introduced.

It may be found when using some triodes that grid current will not flow, a condition essential to the grid detector, unless the grid is slightly positive with respect to the negative end of the filament. Under these conditions it is usual to connect the grid leak between the grid and the positive end of the filament.

What do you understand by the term intervalve coupling? Name the three methods of intervalve coupling, and illustrate each with a diagram.

An intervalve coupling is the circuit between any two valve circuits, to ensure that the signals are passed from one valve circuit to the next without distortion.

The three methods of connecting valves together are:

    (1) Resistance capacity coupling.
    (2) Choke capacity coupling.
    (3) Transformer coupling.

Figs. 41 (*a*), (*b*) and (*c*) show respectively:

A two-stage resistance capacity coupled amplifier; a two-stage choke capacity amplifier and a two-stage transformer coupled amplifier.

What is the chief difference between intervalve coupling for radio-frequency amplification and intervalve audio - frequency coupling. Give a circuit diagram of a two-stage radio-frequency

Audio frequency amplifier using resistance capacity coupling.
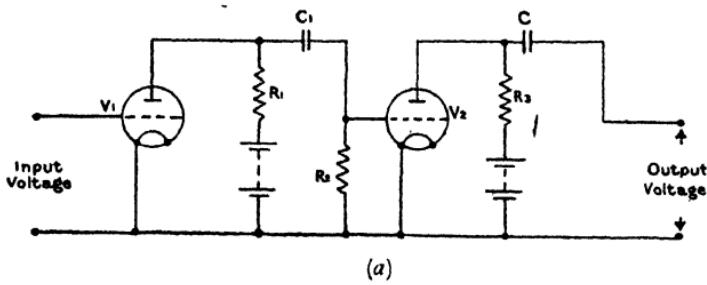
(a)
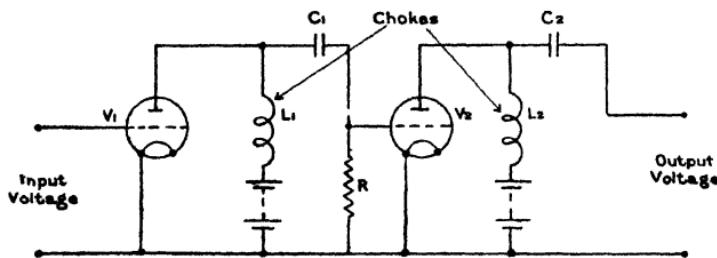
Audio frequency amplifier using choke capacity coupling

(b)

Audio frequency amplifier using transformer coupling.
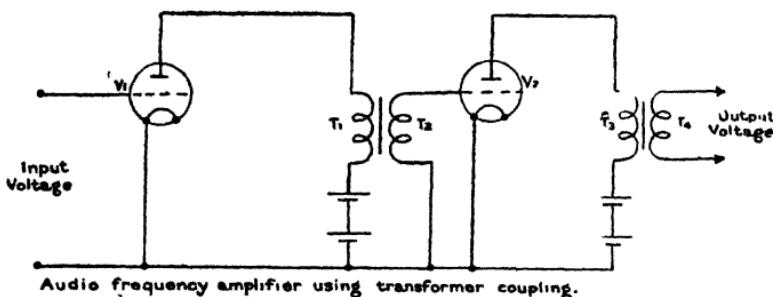
(c)

FIG. 41.

transformer-coupled amplifier and explain its operation.

The intervalve couplings used for radio-frequency amplifiers are invariably tuned circuits, whereas the intervalve coupling used for audio-frequency amplification need not be tuned.

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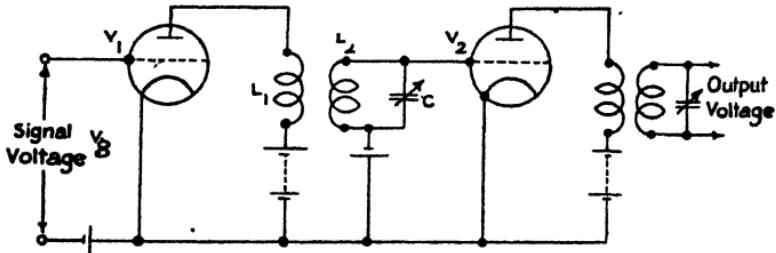
FIG. 42.

Fig. 42 is a circuit diagram of a two-valve radio-frequency transformer-coupled amplifier. The input signals are applied between the grid and filament of valve V_1, resulting in current variations in the primary coil L_1 of the intervalve transformer. Let the mutual inductance between the primary and secondary coil be denoted by M then the voltage induced in the coil L_2 is equal to $\omega M I_a$ where I_a is the value of the oscillatory anode current of valve V_1. The secondary circuit consisting of the coil L_2 and the variable condenser C is adjusted to resonate with the signal frequency resulting in a maximum current in the secondary circuit. The voltage applied to the grid of V_2 will therefore be the resultant rise in voltage of the tuned secondary circuit. The value of this amplified voltage will be $Q\omega M I_a$. where Q is the efficiency of the coil, being the ratio of the coil reactance to the coil resistance

i.e. $\dfrac{\omega L}{R}$.

Describe briefly the screen grid valve or tetrode. What is the function of the respective electrodes? How does the amplification of this type of valve compare with that of an ordinary triode. What is the reason for the introduction of the screen grid?

The screen grid or tetrode is a four-electrode valve (Fig. 43), consisting of a filament or cathode, a control grid, a screen grid and an anode. The control grid performs a similar function to the grid in the triode

valve and is therefore placed nearest to the cathode. The electrons which are emitted from the cathode when it is heated pass to the anode or collector plate via both the control and screen grids, the screen grid is capable therefore of influencing the flow of electrons, depending of course upon the potential of the screen grid with respect to the anode. The main reason, however, for the introduction of the screen electrode is to reduce the inter-electrode capacity between the cathode and anode plates. When triode valves are used in radio-frequency ampli-
fying stages the amplifier is liable to burst into self-oscillation due to retroaction through stray capacitances between anode and grid circuits and in particular through the capacitance existing between the anode and grid themselves. This effect is eliminated by interposing a screen or further grid between the anode and the control grid and applying a fixed D.C. potential to it. The function of the screen grid, therefore, is to eliminate the grid/anode capacitance of the valve.

FIG. 43.

The amplification factor of this type of valve is considerably higher than that of a triode valve.

Draw a typical anode volts/anode current curve of a screen-grid valve, fixed screen voltage to be 80 and the grid bias one volt. With the aid of the curve explain the meaning of the term secondary emission.

Fig. 44 represents a typical anode volts anode current characteristic curve of a screen-grid valve. At first the electrons are attracted to the screen grid and remain there, none flowing to the anode because of its low potential.

As the anode potential is increased, however, a few

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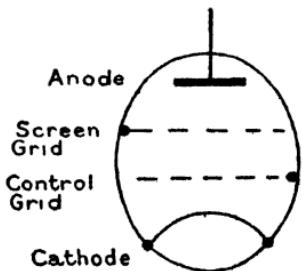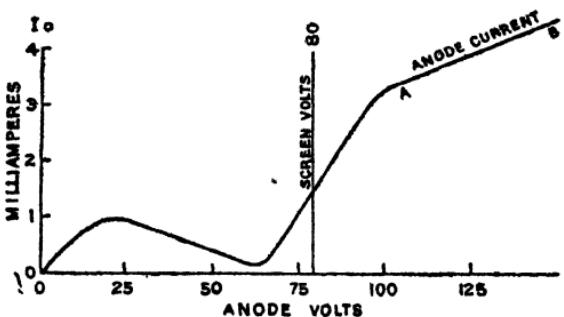
FIG. 44.

electrons commence to reach the anode causing a
current to flow. It will be seen from Fig. 44 that at this
stage the current commences to rise steeply with each
increase in anode voltage. As the anode potential is
increased still further, the electrons striking the anode
will cause secondary emission, i.e. will rebound and
since the screen is positive to the anode, will be attracted
back to the screen. The anode current will therefore
decrease once more until the anode potential becomes
almost equal to that on the screen. When the anode
potential exceeds the screen potential electrons re-
bounding from the anode will not be attracted to the
screen, but will return to the anode, causing the current
to rise once more. The working part of the char-
acteristic is that between points *A* and *B*.

Explain how the grid of a variable-mu valve differs from that of an ordinary screen grid valve. Explain how the variable-mu effect is achieved.

The pitch of the control grid wire in an ordinary
screen grid valve is constant throughout, whereas the
pitch of the wire at one end of the control grid of a
variable-mu valve is different from that at the other
end. The degree of control over the anode current
depends upon the closeness of the mesh or pitch of the
wires forming the grid. The closer the grid wires are
placed together, the greater will be the control

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exercised by the grid, and with it the mutual con-
ductance of the valve. It follows, therefore, that with
the variable-mu valve the degree of control and thus
the mutual conductance would be different on the
portions of cathode stream emerging from the re-
spective lengths of the cathode surrounded by these
two grid sections. The variable-mu anode-current/grid
voltage curve is therefore a combination of two curves,
one less steep than the other.

*What is a variable-mu valve? How do its
mutual characteristics vary from those of the stan-
dard screen-grid valve? What is its main applica-
tion in a wireless receiver?*

A variable-mu valve is one in which the mutual
conductance varies smoothly with changes in grid
bias. Fig. 45 shows the mutual conductance char-
acteristic curves of an ordinary screen-grid valve and
a variable-mu valve.

Considering the ordinary screen grid curve Fig. 45,
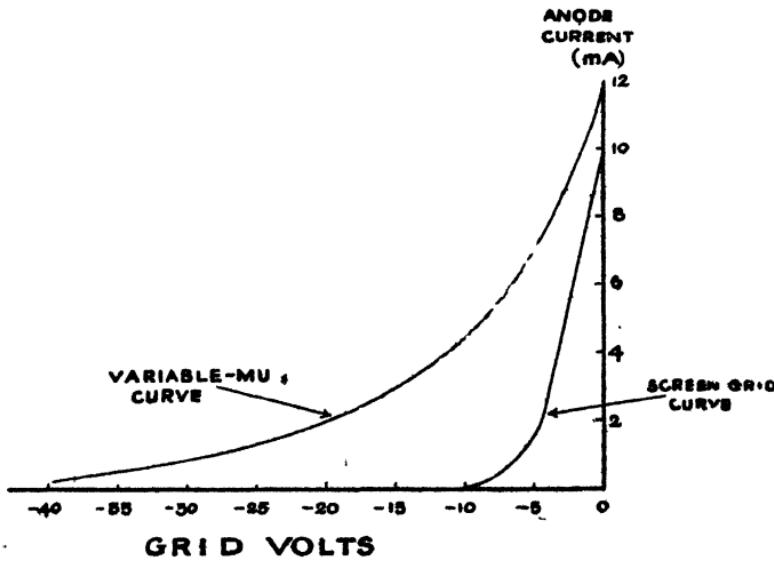
FIG. 45.

it will be seen that when the grid bias exceeds — 8 volts, there will be no anode current flowing. This means that if an incoming signal causes the grid voltage to fluctuate more than −8, no corresponding variation will be produced in the anode current, resulting in distortion. On the other hand, with the variable-mu curve, the anode current is reduced very slowly, enabling the input-grid to handle up to − 40 volts before the zero anode current condition is reached. Thus the distortion mentioned in the case of the straight screen grid is prevented in the variable-mu valve.

The variable-mu valve is used extensively in wireless receivers as the volume control element, because of its wide range of amplification.

Draw a diagram of the electrode assembly of a pentode valve. How does it differ from the screen-grid valve? Compare the characteristic curves of the screen-grid and pentode valves. In what part of a circuit are pentodes usually employed?

THE PENTODE
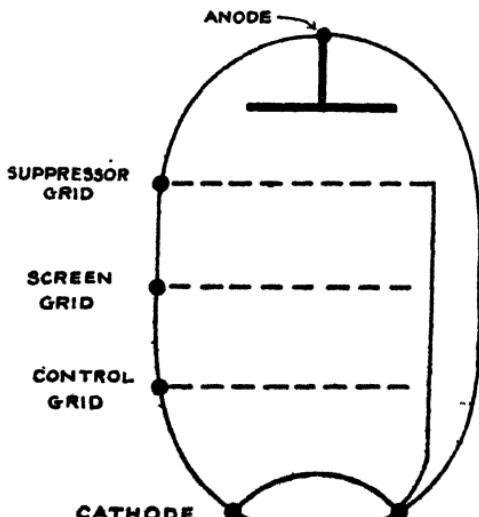
FIG. 46.

Figs. 46 and 47 show the arrangement of the electrodes in a pentode valve. It differs from the screen-grid valve in that an additional screening grid is interposed between the control grid and the anode to prevent secondary emission effect, which occurs in screen grid valves.

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SCREEN GRID   CONTROL GRID   SUPPRESSOR GRID

ANODE

CATHODE
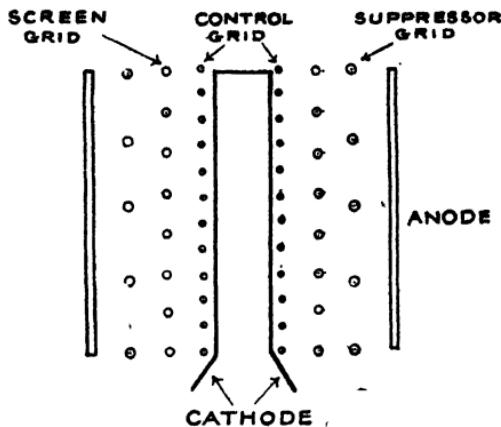
FIG. 47.

A pentode characteristic curve (full line) compared with a screen-grid characteristic curve (broken line) is shown in Fig. 48.
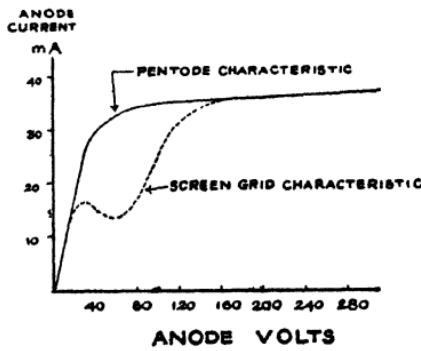
FIG. 48.

A pentode has a high amplification factor and can handle relatively large outputs, and is therefore largely employed in the output stages of a receiver. High-frequency pentodes are in use in H.F. circuits where a comparatively large output is required.

Explain the action of the suppressor grid in a pentode valve.

The suppressor grid in a pentode valve is maintained at a potential which is considerably negative with respect to both the screen and anode (cathode potential). Thus, when the anode voltage is lower than that of the screen grid and emits secondary electrons due to bombardment by the electron stream coming from the cathode, these secondary electrons will not be attracted by the screen because of the interposition of the negative potential on the suppressor grid. This negative potential on the suppressor grid causes the secondary electrons to be repelled back to the anode, thus the kink which is present in the characteristic curve of a screen-grid valve caused by the passage of electrons from the anode to screen is prevented (see curves, Fig. 49). By removing this kink a considerable increase in the output voltage swing available from the valve can be obtained.

Sketch the electrode assembly of a double-diode-triode valve.

Draw two simple circuits incorporating a double-diode-triode valve, and explain the operation of one of them.

FIG. 49.

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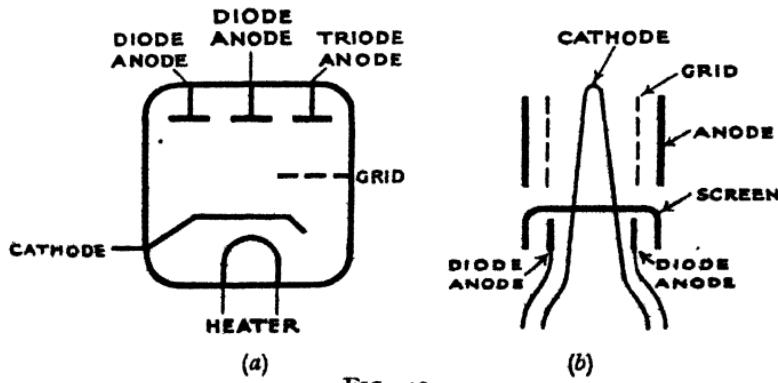
Figs. 50 and 51 are two circuits which incorporate the double-diode-triode valve. Fig. 50 shows the valve acting as a full wave rectifier and amplifier while in Fig. 51 the valve is connected to provide automatic volume control. In the latter case the double-diode-triode valve is connected for signal detection by D_1, low frequency amplification by the triode section, and production of automatic volume control (A.V.C.) voltage by diode D_2. Fig. 50 only shows the relevant A.V.C. circuit.

Operation.

Signal voltage is coupled by condenser C_1 from the intermediate frequency (*I.F.*) amplifier anode to the A.V.C. diode anode D_2. This anode is biased negatively by the voltage drop in R_1 in the main H.T. negative-lead of the receiver.
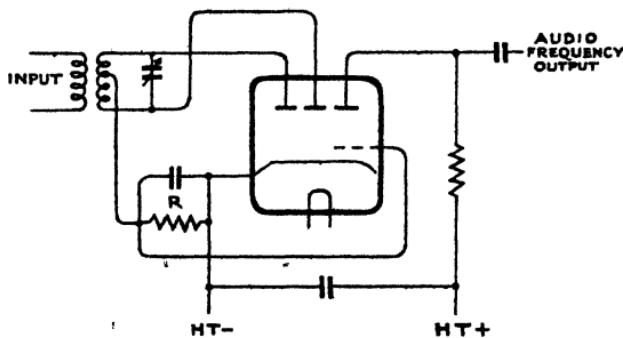
FIG. 50.

Automatic bias is this produced in R_1 and R_4, which are by-passed by the electrolytic condenser C_4. The full voltage drop in these two resistances may conveniently be used for the bias of the output valve. Negative bias for the A.V.C. diode is applied via the load resistance R_3. Rectified current from D_2 passes through resistance R_3 and the voltage so developed is applied to the amplifier valves through resistance R_2, which, with condenser C_2 forms the filter. With this arrangement the delay bias is applied also to the
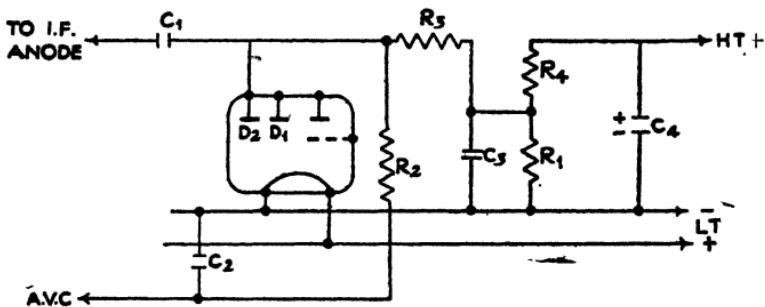
DELAYED A.V.C. FOR BATTERY RECEIVER

FIG. 51.

controlled valve as grid bias, so that this circuit may provide the minimum bias for these valves.

Give a brief description of the triode-pentode valve and draw a simple circuit incorporating this valve.

Figure 52 shows the arrangement of the electrodes of
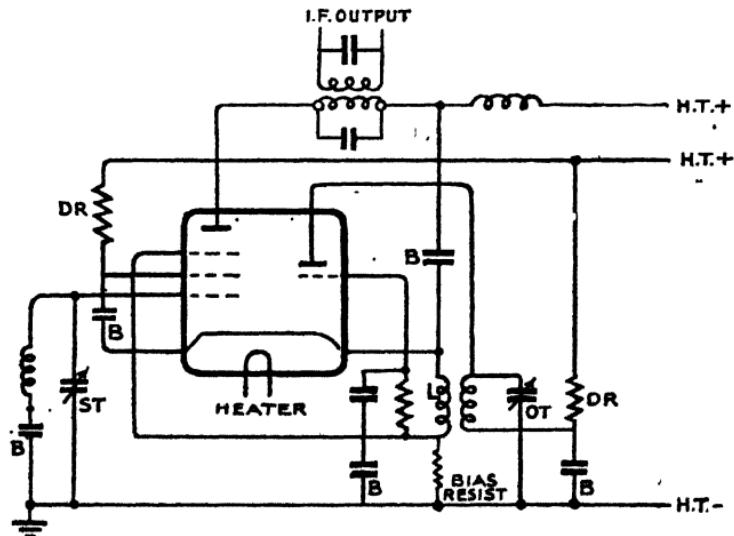
FIG. 52.

a triode-pentode valve. The triode pentode is a frequency changer. It consists of a triode oscillator and a pentode mixer within one envelope. The pentode section has variable-mu characteristics, the suppressor grid acting as the oscillation injector grid. Variable conversion gain is controlled by the biasing voltage applied to the first grid of the pentode. A parallel feed circuit is employed for the oscillator, with tuned anode circuit. Coupling of the oscillator and mixer is by the common coil L.

Indicate diagrammatically the arrangement of the electrodes in a pentagrid valve. Explain the action of the valve when functioning as a frequency changer.

Figure 53 shows the arrangement of the electrodes in a pentagrid valve.

It will be seen upon inspection that the valve consists of two sections:
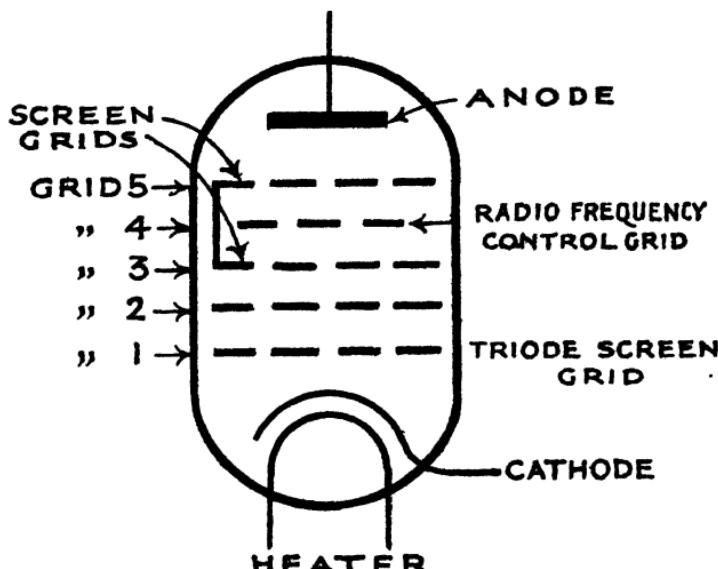
FIG. 53.

(1) The triode section—consisting of the cathode and the first two grids, and

(2) A tetrode section—consisting of the anode and grids three, four and five.

When the valve acts as a frequency-changer, the triode section acts as an oscillator. The second section acts as a screened tetrode, with emission from the second grid of the triode section modulated at the oscillator frequency. In the tetrode the modulated emission is again modulated by the signal which is impressed upon the fourth grid.

The anode circuit accepts the intermediate frequency and passes this component of the modulation-products to the succeeding amplifier valve. The tetrode is designed to have "variable-mu" characteristics and the sensitivity can therefore be controlled by the grid bias voltage applied to the fourth or radio frequency control grid. The screening grids cause the valve to have a high A.C. resistance and a high conversion gain when the anode load impedance is high.
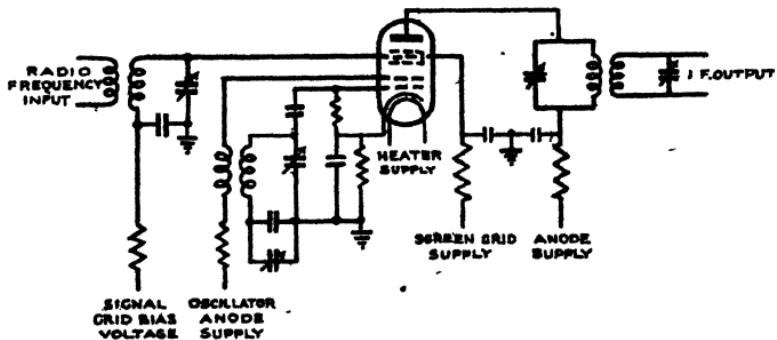
FIG. 54.

Fig. 54 is a circuit containing a pentagrid valve acting as a frequency changer in a superhet receiver.

Draw the arrangement of the electrodes of a triode-hexode valve. What is the function of this

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type of valve? How is the internal coupling be-
tween the two sections of the valve obtained?

Fig. 55 clearly illustrates the various electrodes in a triode-hexode valve. It consists of two separate electrode assemblies—a triode section and a hexode section—having a common cathode. The valve acts as a frequency-changer, the triode portion acting as the oscillator and the hexode as the mixer. Internal coupling is provided by connecting the grid of the triode to one of the grids of the hexode.
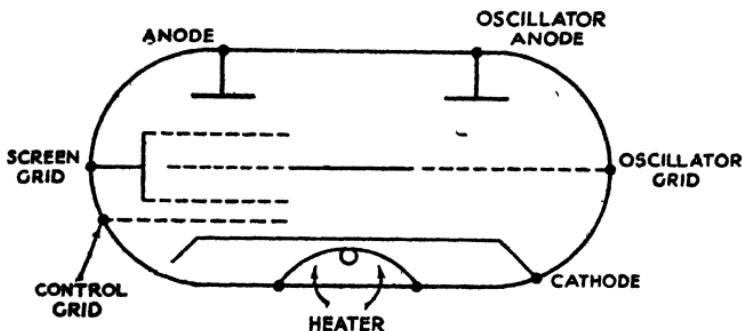
THE TRIODE HEXODE

FIG. 55.

What is meant by a " distorted wave-form "?
Show with the aid of curves how distortion can be
avoided by adjusting the working point on the
mutual characteristic curve of the valve.

Distortion is the change in shape of the transmitted wave which occurs due to line or apparatus. For instance, distortion is caused in an amplifier if the shape of the wave at the output is not the same as that at the input. The magnitude of the wave, of course, will be greater at the output side, but the actual shape of the wave should not vary. The first require-ment for distortionless amplification is to ensure that

ANODE CURRENT
VARIATIONS

WAVES CUT (DISTORTED)

GRID VOLTAGE
VARIATIONS

Fig. 56.

ANODE CURRENT
VARIATION

UNDISTORTED WAVE

GRID VOLTAGE
VARIATION

Fig. 57.

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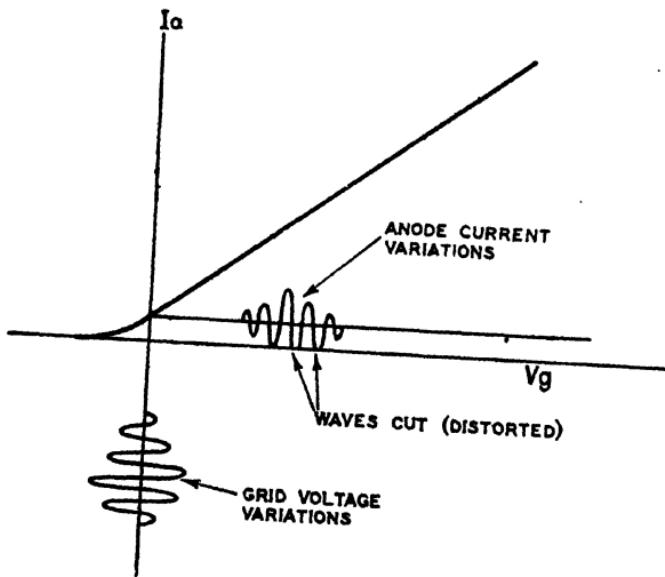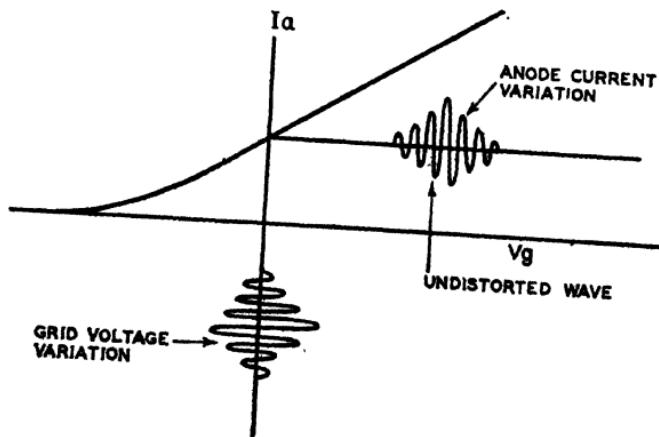
a linear relation exists between grid voltage and anode current of the amplifying valve. Fig. 57 shows a valve so biased that distortion is introduced due to non-lineality between grid voltage and anode current, or in other words, due to working on the lower bend of the grid volts anode current curve; the anode current variations and hence the output wave-form is asymmetrical and distorted.

This type of distortion is overcome by adjusting the constants of the valve so that any grid swing produces anode current variations on the straight portion of the characteristic as shown in Fig. 57.

CHAPTER IV

RECEIVERS

What is a crystal detector? How may this apparatus be employed for the reception of electromagnetic signals?

The crystal detector is a form of "one way" device or rectifier, especially suited to the rectification of very small radio-frequency voltages.

The most common forms of crystal detector are· as follows:

(1) Galena crystal with phosphor-bronze "catswhisker."

(2) Zincite-bornite crystal couple.

(3) Carborundum crystal with steel spring.
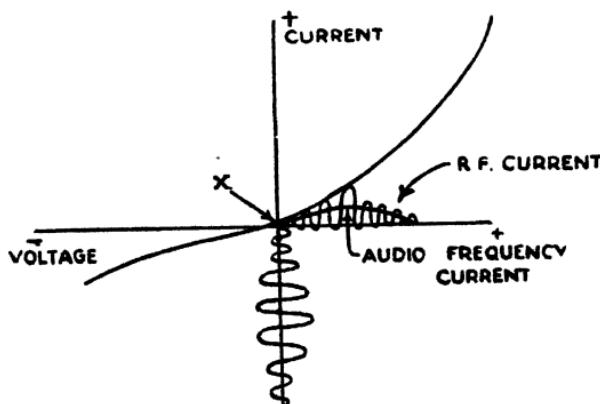
FIG. 58.

Fig. 58 shows the characteristic curve of a typical crystal detector. The characteristic curve is a graph of the crystal current plotted against applied voltage.

If the operating point of the crystal is adjusted to

"*X*" it will be seen that application of a symmetrical voltage produces an asymmetrical current.

Some crystal combinations, for example (1) and (2) above, find their working point automatically, but others such as (3), carborundum and steel, require application of a small external polarising potential before rectification may be achieved.

A simple circuit for the reception of electro-magnetic waves by means of a crystal detector is illustrated in Fig. 59.

Variable condenser C_1 in conjunction with fixed inductance L_1 permits the receiver to be tuned to the required transmission.

Electro-magnetic waves in the aerial set up a varying radio-frequency potential across L_1 and C_1, this potential also being applied across the crystal couple via the radio-frequency by-pass condenser C_2.

FIG. 59.

The audio-frequency currents produced by the detector flow through the windings of the telephones, and the resulting movements of the diaphragms set up sound waves corresponding to the modulation of the radio-frequency signal.

Why is it necessary to use a detector in the reception of modulated radio-frequency wave-trains? Amplify your answer with suitable diagrams showing the effect of rectification.

When the amplitude of a radio-frequency wave-form is controlled by a speech frequency known as audio frequency, it is said to be modulated, and in this way intelligence can be transmitted. Although the amplitude of the radio-frequency waves has been varied the
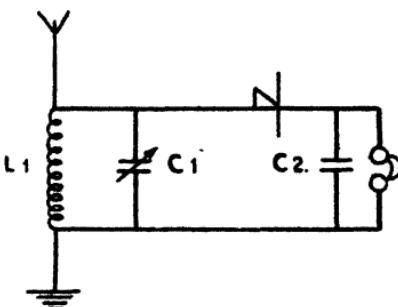
frequency at which they radiate is only slightly altered, and in order to understand the message transmitted, the receiver after tuning to the frequency of the transmission must suitably convert the modulated high-frequency wave-form so that the intelligence is conveyed either by audio frequencies to the ear, or by some scanning device to the eye. This is brought about by rectifying the modulated signal and obtaining a pulsating direct current which varies in magnitude in accordance with the original modulation frequency. Such a process is known as "detection" or "rectification," and is necessary because a pair of telephones, for instance, if inserted in the tuned circuit alone, would not respond to the high-frequency current due to the high impedance of the coils, and also the diaphragm would not vibrate at such a high frequency. In addition, the human ear is not capable of responding to radio-frequency vibrations, being limited to sounds caused by air vibrations between 16 and 20,000 cycles per second.

(a)   Modulated wave applied to detector

(b)   After rectification

(c)   Current which operates headphones
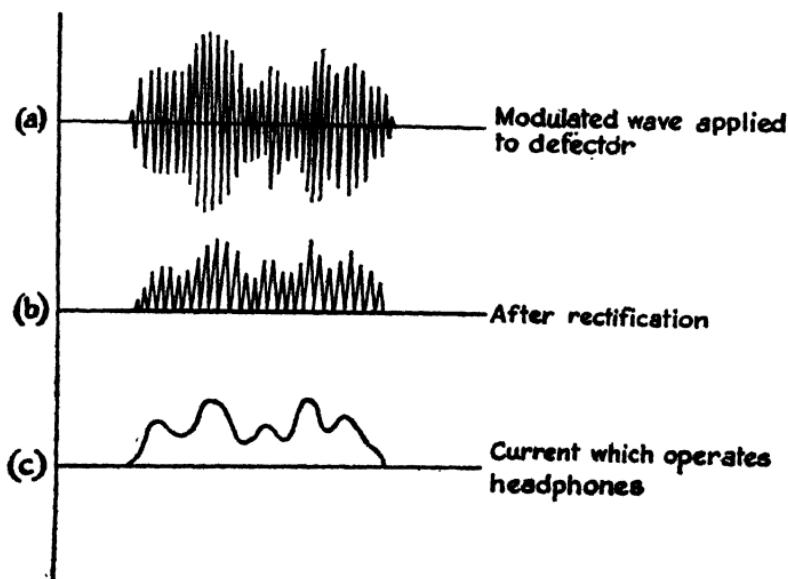
FIG. 60.

The pulsating direct current, due to rectification, is the cumulative uni-directional component of the wave-form and may be made to vibrate a telephone diaphragm in accordance with the strength of the current.

Fig. 60 (*a*) shows the voltage variations of a wave train applied to the rectifier. Fig. 60 (*b*) shows the current through the detector. Fig. 60 (*c*) shows the resultant cumulative uni-directional current which actuates the telephones at the modulation frequency.

A simple receiver is required for the reception of a local, medium-wave broadcasting station.

Draw the circuit diagram of a suitable instrument, giving reasons for your choice.

Since reception of a local station only is required, inclusion of a radio-frequency amplification stage will not be essential as the ratio of wanted to unwanted signal will be high.

Again, the comparatively high field strength will result in a large detector output, sufficient to load an output pentode, an audio-frequency stage not being required.

A suitable circuit would thus comprise a triode detector with reaction, and an output pentode feeding an energised loudspeaker, the energising coil being utilised for smoothing the H.T. supply.

As reception of one station only is required, the tuning and reaction condensers may be of the pre-set type, the only external control being a combined volume control and on/off switch.

Fig. 61 shows the circuit arrangements, $V1$ and $V2$ being an indirectly-heated triode and pentode respectively.

Describe with the aid of a block schematic diagram, the operation of a Super-heterodyne receiver suitable for the reception of Radio Telephony.

The general principle involved in the operation of a superheterodyne receiver is to heterodyne or beat the

Fig 61.

94
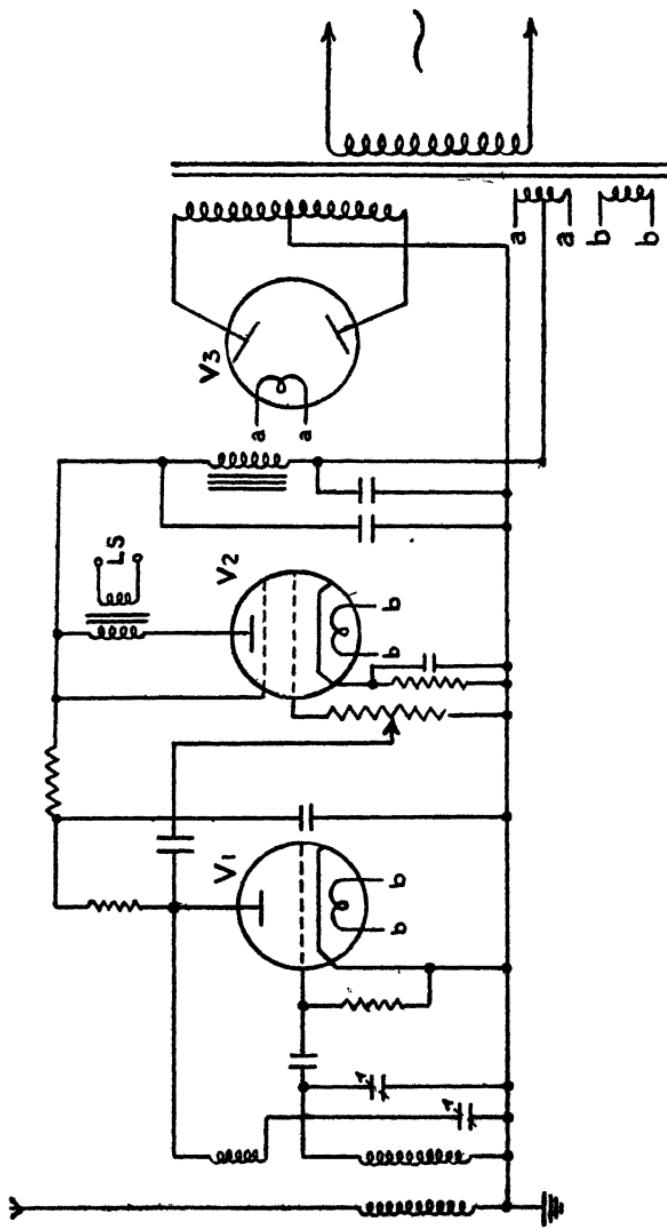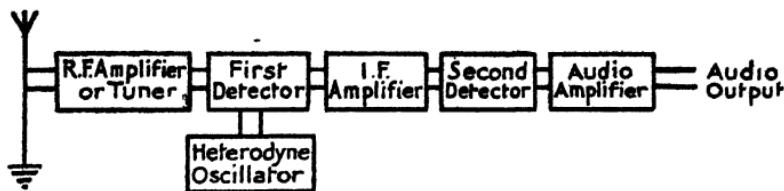
FIG. 62.

incoming radio-frequency wave against the radio-frequency wave produced by a local oscillator. The frequency of the local oscillator is chosen to ensure that the frequency difference between the two oscillations i.e. the intermediate frequency (IF) is well above the audio limit, i.e. of low radio frequency or supersonic.

The oscillation resulting from the beating of the two frequencies is rectified by the 1st detector, the R/F component is by-passed whilst the I/F component is passed to the I/F amplifier and then to the 2nd detector. The I/F output component of the 2nd detector is by-passed whilst the A/F component is amplified by the A/F amplifier and passed to the loud-speaker or telephones.

The R/F amplifier is added to improve the sensitivity and selectivity of the receiver in addition to isolating the local oscillator from the aerial system, thus preventing interference with adjacent receivers.

Special I/F transformers are utilised to couple the 1st detector and I/F amplifier which are designed to have a sharp cut-off above and below the I/F band width required. Interference from unwanted signals is therefore reduced to a minimum.

Suppose the receiver is tuned to a wavelength of 200 metres (1500 Kc/s) and the heterodyne frequency is 1450 Kc/s, the I/F being 50 Kc/s. Another signal on the adjacent frequency of 1510 Kc/s would produce an I/F of 60 Kc/s which would be readily rejected by the I/F circuits tuned to 50 Kc/s. If, however, a signal is received on a frequency of 1400 Kc/s, it will be seen that the I/F will again be 50 Kc/s, which will

be passed to the I/F amplifier and subsequent stages. Interference received on the second frequency which produces the same I/F as the wanted signal is termed second channel interference.

The tuning of the R/F stage would need to be extremely selective to differentiate between 1400 and 1500 Kc/s. In practice second channel interference is eliminated by the careful choice of heterodyne frequency.

What is the usual choice of I/F for the following superheterodyne receivers:
    (a) Medium wave W/T?
    (b) Medium wave commercial R/T?
Give your reasons.
What Intermediate Frequencies are chosen for Short Wave W/T and R/T receivers respectively?

The choice of intermediate frequency for a superheterodyne receiver determines to a great extent the selectivity of the receiver and depends upon the use for which the apparatus is intended.

The two most common types of interference affecting superheterodyne receivers are:
    (1) Adjacent channel intererence.
    (2) Second channel interference.

In the case of a medium-wave receiver designed for the reception of W/T signals, the I/F is generally 40 Kc/s with 20 Kc/s as the lower limit. The use of this frequency ensures low adjacent channel interference and by providing separate control of the heterodyne oscillator frequency, second channel interference can be readily eliminated.

To illustrate numerically.

Suppose the receiver is tuned to 800 Kc/s with a heterodyne frequency of 760 Kc/s, an unwanted transmission on 810 Kc/s would produce an I/F of 50 Kc/s, which would be readily rejected by the I/F transformer tuned to 40 Kc/s. If second channel interference was experienced from a transmission on 720 Kc/s, adjust-

ment of the heterodyne frequency to 840 Kc/s would eliminate the interference.

Next to consider a commercial medium wave R/T receiver. To simplify operation it is not usual to afford separate control of the heterodyne oscillator, but as a very high degree of adjacent channel selectivity is not generally required, it is possible to obviate second channel interference by utilising a much higher I/F, 450 Kc/s being a very common value.

Suppose the receiver is tuned to 800 Kc/s and the heterodyne oscillator is adjusted to 350 Kc/s, the frequency of second channel interference which would produce an I/F of 450 Kc/s would be 1250 Kc/s, a frequency readily rejected by the R/F tuned circuits.

In the case of H/F (short wave) receivers, common values of I/F are as follows:

   (a) 120 Kc/s for W/T receivers.
   (b) 450/500 Kc/s for R/T receivers.

In the very latest types of H/F R/T receivers, intermediate frequencies as high as 1600 Kc/s are frequently employed.

Quality of reproduction in the early types of superhet receiver was poor, owing to the sharp selectivity reducing the intensity of high notes. Explain with the aid of a diagram how this trouble was overcome.

This early troublesome effect was overcome by the arrangement shown in Fig. 63.

The coils L_1 and L_2 of the intermediate frequency transformer were tuned by condensers C_1 and C_2 respectively, forming two coupled tuned circuits. For distant reception the arrangement had to be highly selective, but this was not necessary for the strong local stations. To enable the listener to obtain better quality on local reception, resistances R_1 and R_2 were introduced into the tuned circuits by means of switches S_1 and S_2. As will be seen from Fig. 63 R_1 is in parallel with the primary tuned circuit and R_2 in series with

the secondary tuned circuit. When these resistances are introduced into the circuit the gain of the stage was reduced to about one-twentieth of that given when they are out of circuit, but at the same time the selective tuning peaks are flattened considerably and a band-pass filter effect obtained, resulting in improvement of quality.
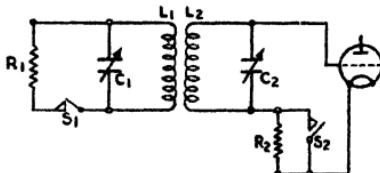
FIG 63.

Amplify the phrase " correct loudness " as applied to a radio receiver. What are the power requirements of a modern receiver to obtain correct loudness?

"Correct loudness" plays a very important part in radio reception. For correct loudness what is needed is the same sound strength at the listeners' ear as at the original performance.

The power actually needed to produce this depends on the size and acoustic properties of the room, and to some extent on the listener's taste. Some concert-goers prefer a back seat in the upper circle, others a stall near the conductor. Naturally "the original performance " is a much louder thing for the latter than the former; but which ever it may be, that is the correct standard to work to.

The power necessary to produce this effect is even more variable; for it depends on the loud-speaker and its position as well as on the room and the listener. It has been found from experience that to allow for occasional loud orchestral crashes without distortion and give a comfortable feeling of power in hand, when wanted, the undistorted output of the receiver should be approximately one to two watts for the average sized room of a house.

Describe one method of Push Button Tuning.
Why is this form of tuning unsatisfactory on the short-wave bands?

The Push Button tuning system illustrated in Figs. 64 and 65 utilises an electric motor which, on depression of a button, rotates the condenser vanes to the correct tuning position of the station selected.

The electrical equipment consists of a strip of push buttons fitted with normal and operate contacts, an insulated disc carrying two metal half-plates separated

FIG. 64.

FIG. 65.

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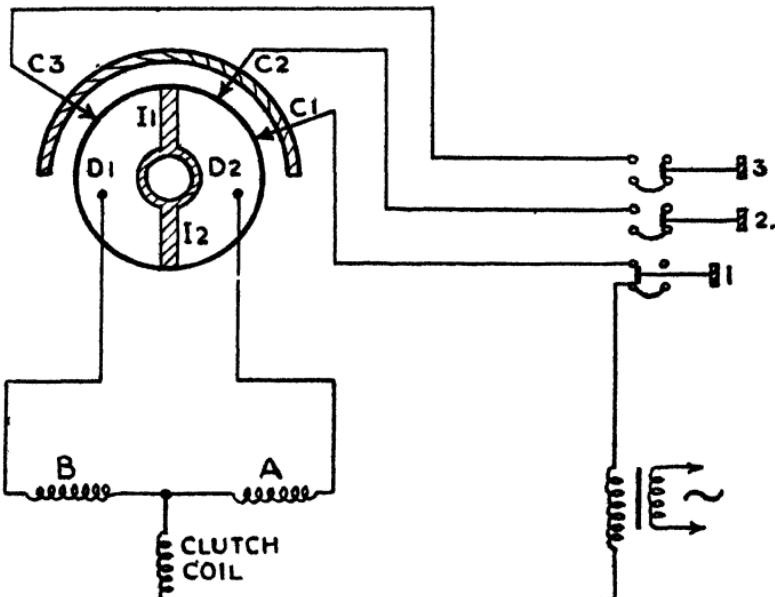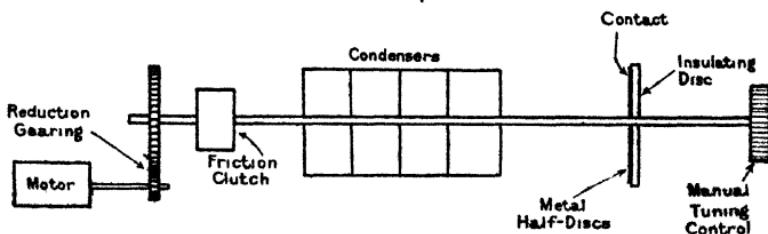
by insulating gaps, mounted on the condenser shaft, and an insulated semi-circular ring carrying the same number of adjustable contact fingers as there are push buttons. The electric motor has two windings, one for clockwise and the other for anti-clockwise rotation. A magnetic clutch is incorporated in the motor drive, the latter rotating the condenser shaft via reduction gearing.

The push buttons are mechanically interlocked so that a depressed button remains in that position until a second button is operated, when the first is restored.

Power for the motor and magnetic clutch is derived from an additional winding on the mains transformer.

Suppose Button No. 1 is depressed.

A circuit for motor coil A and the magnetic clutch is completed via Contact C_1 and half-disc D_2. The motor starts up and operation of the clutch permits rotation of the shaft in a clockwise direction until insulating gap I_1 rides beneath C_1, when the clutch and motor are de-energised and rotation ceases. Rapid action of the clutch minimises the possibility of overrunning so that C_1 makes contact with half-disc D_1; should this occur, however, motor coil B (and the clutch) will be energised and the shaft rotated in an anti-clockwise direction until C_1 rests on the insulating gap. As contact C_1 has been adjusted to rest on the insulating gap when the condenser vanes are in the exact tuning position for the selected station, it will be seen that depression of Button No. 1 causes the condenser vanes to rotate until that station is "tuned in."

Push-button tuning of a short-wave receiver cannot be satisfactorily accomplished by the above or any other reasonably inexpensive method, as the requisite tuning accuracy is unobtainable.

What do you understand by automatic volume control? Why is common automatic volume control used with diversity receivers?

Automatic volume control is a feature incorporated

FIG. 66.

Output

Aerial "A"

Unit combining V.F. outputs & A.V.C. systems.

Common frequency change oscillator

To Aerial "A"

Receiver "A"

Receiver "B"

Receiver "C"

To Aerial "C"

To Aerial "B"

Aerial "B"

Aerial "C"
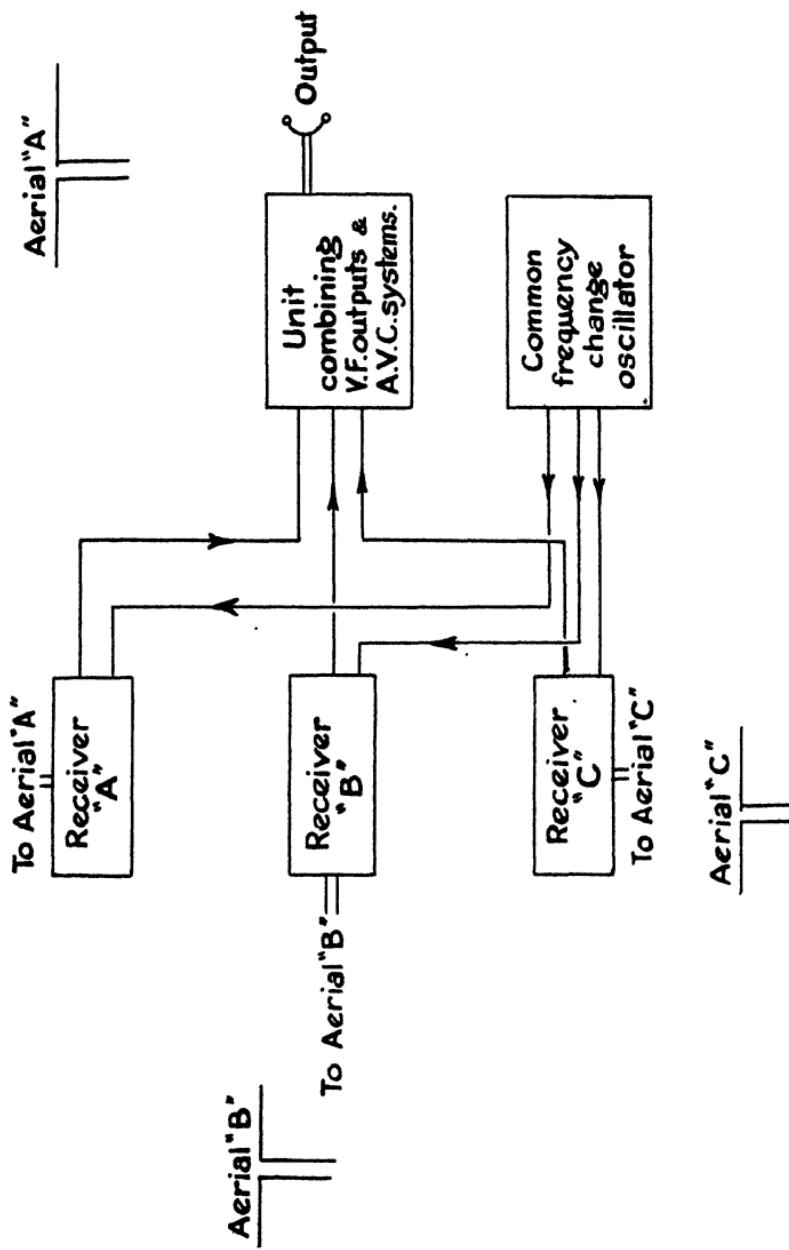
in the circuit whereby the amplification of the receiver is controlled by the signal being received so that the output of the receiver remains sensibly constant, i.e. the greatest amplification is obtained when the incoming signal is weak. Changes in signal strength due to fading are thereby automatically compensated for. This is achieved in the following manner. The voltage produced by the signal at the output of the detector valve is fed back as grid bias to the high-frequency amplifying valves and controls their amplification. Variable-mu valves are used for this purpose.

When the required signal is fading, one or perhaps more of the aerials are providing very little energy to their respective receivers and therefore contribute little or nothing of the signal to the common V.F. output. Nevertheless they still provide their quota of "noise" to the output. In other words conditions will arise where all the receivers contribute noise but only one receiver is contributing the wanted signal to the combined output. By using a common A.V.C. voltage for all receivers the final output is chosen automatically

AUTO BIAS TO
GRID CCT. OF
1st VALVE
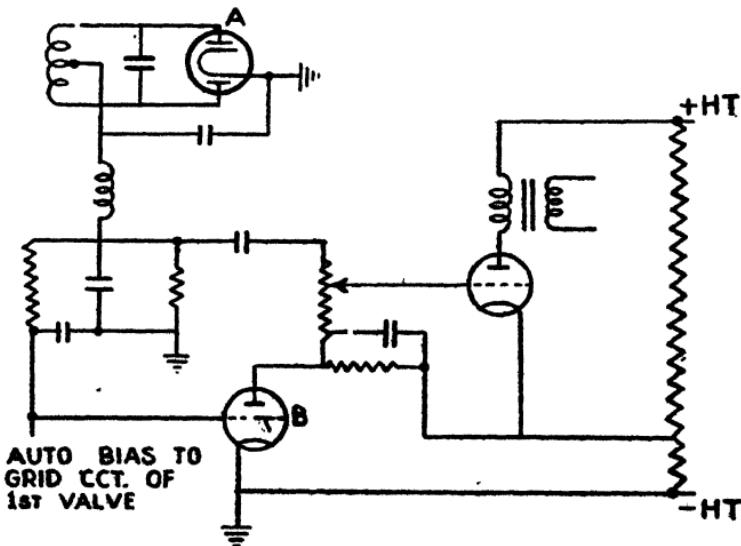
FIG. 67.

from the receiver or receivers giving the best results. In effect the A.V.C. voltage provided by the receivers experiencing the strongest signal will reduce the R/F gain of the receivers that are more or less idle, thus partially shutting them down until they again receive the desired signal at sufficient strength to be of value to the combined output. Fig 67 shows a suitable A.V.C. control.

Explain briefly what you understand by " Diversity Reception." Why use Diversity Reception?

This is the term applied to the system of reception where two or more receivers are tuned to one frequency. The "outputs" of the receivers normally being combined to give a common voice frequency output. The receivers would have their own aerial systems and the aerials should have separate locations, being spaced by as great a distance as the available site will allow. For H/F work competent authorities suggest that aerials should be spaced about 15 wavelengths apart in all directions. In practice spacing of 1,000 feet gives excellent results, but much closer spacing may be used without losing all the advantages of the "diversity" system.

To assist in overcoming the phenomenon of fading which is more serious at the higher frequencies. In general this fading is due to an interference effect produced by waves arriving at the receivers having followed paths of different lengths from the transmitter. Single receivers placed a few hundred feet apart experience different degrees of fading when tuned to the same signal. It therefore follows that grouping the receivers into one unit with the aerials of each receiver spaced a few hundred feet apart will enable each aerial to be influenced by the wave at different periods of the fade. A fading signal will give each receiver via its own aerial, a different input. This "input" is amplified in the ordinary manner and the outputs combined to give a far greater constancy of signal level than

could be obtained from a single aerial and receiver. The whole object of diversity reception is to obtain as far as possible a constant signal level from the receivers.

What is the purpose of negative feed-back in an audio-frequency amplifier? Show by a diagram how it is applied and explain the manner in which negative feed-back achieves its object.

Negative feed-back is used in an audio-frequency amplifier to reduce amplitude distortion and noise, and to reduce variations of gain resulting from variations of supply voltages and valve constants. It may also be used to reduce frequency distortion or to equalise frequency distortion in other equipment.
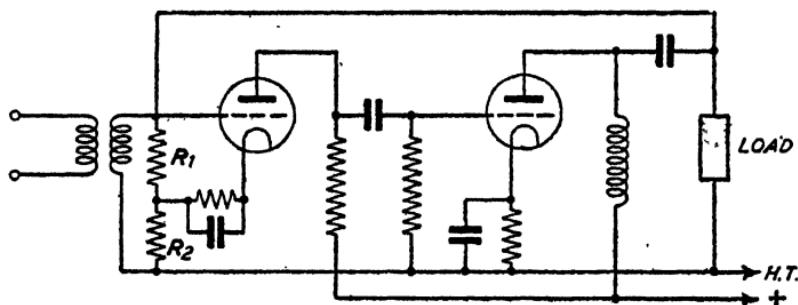

Fig. 68.

A two-stage triode, resistance capacity coupled amplifier with negative feed-back is shown in Fig. 68. A current proportional to the load is fed through potentiometer R_1, R_2, the drop across R_2 being applied to the grid of the first valve, in series with the input voltage.


INPUT e_s AMPLIFIER GAIN A OUTPUT E

FEED BACK βE

Fig. 69.

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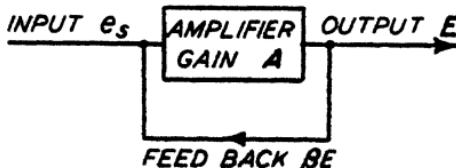
Fig. 69 is a block diagram illustrating the principle of operation of negative feed-back. A fraction βE of the output voltage E is fed back and applied in series with the input voltage e_s.

The sign of β is such that if the net input level is reduced by feed-back, β is negative. Let A be the amplifier gain without feed-back, then with feed-back the input is $e_s + \beta E$ and

$$(e_s + \beta E)A = E$$

i.e. $$e_sA + \beta EA = E$$

i.e. $$e_sA = E(1 - \beta A)$$

and $$\frac{E}{e_s} = \frac{A}{1 - \beta A}$$

which is the effective gain of the amplifier with feed-back.

If βA is very much greater than one

$$\frac{E}{e_s} = \frac{A}{-\beta A} = \frac{-1}{\beta}$$

That is, the effective gain of the complete network is dependent only upon the fraction β of the output voltage fed back, and is substantially independent of the gain of the amplifier. Since βA may be made large by making β small and increasing A, the advantage of negative feed-back may be realised without necessarily sacrificing gain. In other words, if the gain of a certain amplifier without feed-back is A, it can be replaced by another amplifier of higher gain (A^1), but with negative feed-back, the fraction of output voltage feed-back (β^1), and the value of A^1 being such that the net gain of the complete network $A^1/(1 - \beta^1 A^1)$ is equal to A.

Since, in the circuit of Fig. 68 the value of β is determined by the ratio $R_2/(R_1 + R_2)$ and this is substantially independent of variations in valve constants, supply voltages and signal frequency, any variations in the gain associated with these amplifiers are considerably reduced by the application of negative feed-back. Negative feed-back may be employed in an amplifier for use as an equaliser, by adding reactances

to the circuit R_1, R_2, so that the transmission loss characteristic of the circuit across which the feed-back voltage is developed, is the same as the desired gain characteristic of the amplifier with feed-back. In other words, to correct for frequency characteristics of a network connected in circuit with the amplifier, the feed-back network is designed to have a frequency characteristic identical with that to be corrected.

Reduction of Distortion Generated in the Amplifier.

Let d represent the amount of distortion due to the amplifier and appearing in the output circuit when the signal output is E. Let D represent the reduced amount of distortion appearing in the output circuit when negative feed-back is applied and the gain of the amplifier is increased to give the same signal output E as before. The distortion voltage fed back to the input circuit and amplified A times, is then βD. Then, assuming that all distortion is generated in the final stage, the total distortion output is $D = d + A \beta D$, Hence $D = d/(1 - A \beta)$, or, the use of negative feed-back reduces the distortion in the radio $1/(1 - A \beta)$.

Improvement in Signal/Noise Ratio.

The conditions in two amplifiers, one without feed-back and one with feed-back, are represented in Figs. 70 and 71 respectively.
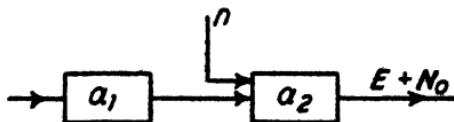
FIG. 70.

It is assumed that all noise is introduced at one point in each amplifier. a_1, a_2 and A_1, A_2 are the gains of the portions of the amplifier; the signal input and the signal output (E) are assumed to be the same in each case; n represents the level of noise at the point where it arises in each amplifier, and N_o and N_f the output
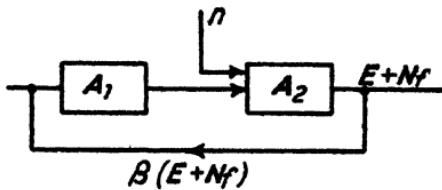
FIG. 71.

noise level without feed-back and with feed-back respectively. Then for the amplifier without feed-back.

$$N_0 = na_2,$$

and the signal/noise ratio is

$$\frac{E}{N_0} = \frac{E}{na_2}$$

For the amplifier with feed-back,

$$Nf = nA_2 + \beta Nf (A_1 + A_2)$$

$$Nf [1 - \beta (A_1 + A_2)] = nA_2$$

$$Nf = \frac{nA_2}{1 - \beta (A_1 + A_2)}$$

and the signal/noise ratio is

$$\frac{E}{Nf} = \frac{E [1 - \beta (A_1 + A_2)]}{nA_2}$$

The improvement in signal to noise ratio may be expressed by

$$\frac{E}{Nf} \div \frac{E}{N_0} = \frac{N_0}{N_2}$$

$$= \frac{na_2 [1 - \beta (A_1 + A_2)]}{nA_2}$$

$$= \frac{a_2}{A_2} (1 - \beta A)$$

where $\qquad A = A_1 + A_2$

The effective gain of the amplifier with feed-back is equal to the gain $(a = a_1 + a_2)$ of the amplifier without feed-back

hence $\qquad a = \dfrac{A}{1 - \beta A}$

If the source of noise is at the input of the amplifier so

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that a_2 is equal to a and A_2 is equal to A, the improvement in signal to noise ratio is given by the ratio

$$\frac{a}{A}\,(1 - \beta A) = \frac{1}{1 - \beta A}\,(1 - \beta A) = 1.$$

That is, no improvement is effected by negative feedback.

If the source of noise is at a late stage in the amplifier, the increase in actual gain to maintain the effective gain equal to a, when negative feed-back is applied, can be made before the source of noise, thus, if the gain A_2 of the portion of the feed-back amplifier following the source of noise is the same as the gain a_2 of the corresponding portion of the amplifier without feedback, the improvement in signal to noise ratio is $(1 - \beta A)$.

How will the post-war broadcast receiver compare with the present set? Mention any transmission change which will affect the receiver of the future.

The receiver of the future will most probably possess three groups of wavebands:

(a) A frequency-modulated band providing superb quality from local stations.

(b) The medium wavebands offering good performance over greater distances.

(c) The high-frequency band giving world-wide reception at a relatively lower quality.

In addition the receiver will most probably be made switchable to permit reception over the wire broadcast system if desired.

This means a greater choice of stations for the listener, it would not be unreasonable to expect the choice of say 20 different home programmes, compared with two from the B.B.C. at present.

Frequency modulation will play an important part in future wireless transmission. If it is assumed that a frequency band of 50 to 60 Mc/s is employed for frequency-modulated transmissions, then, with channel

separation of 250 Kc/s, forty channels could be obtained.

With this separation perfect reception would be obtainable.

What is the function of the Discriminator in a Frequency-modulated receiver?
Describe the Phase Difference Discriminator.

The discriminator or frequency amplitude converter is the apparatus which translates the frequency changes of the received carrier into a current similar to the modulating audio-frequency wave.

The phase difference discriminator consists essentially of a special I/F transformer with tuned primary and secondary windings and a double-diode. The circuit arrangements are shown in Fig. 72.
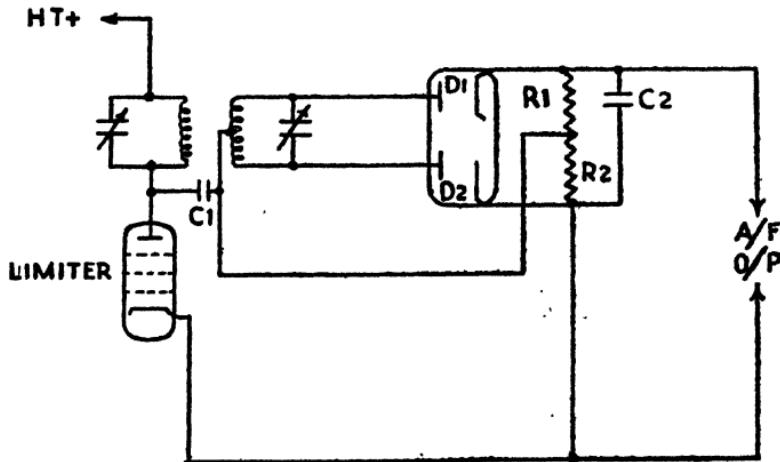
FIG. 72.

The voltage developed across the primary winding is applied to the mid-point of the secondary via condenser C_1. At the transformer resonant frequency (i.e. the receiver I/F) the voltages applied to the diodes D_1 and D_2 will be equal. The rectified output potential appearing across R_1 and R_2 will thus also be equal but opposite in polarity, the A/F output being zero.

If, however, the signal frequency applied to the transformer primary is altered, the voltage applied to one diode, say D_1, is greater than that applied to D_2. A greater potential will thus be developed across R_1 than R_2 and the resultant potential across the output terminals will be positive. A variation of the signal frequency in the opposite direction results in D_2 receiving the greater potential and the output being negative.

The secret of the frequency amplitude converter is to be found in the double excitation of the transformer secondary, one source being via condenser C_1, the other the usual mutual inductive coupling with the primary. At resonance the primary voltage injected through C_1 leads both the induced secondary voltage and current by 90°, but off resonance the phase relationship of the induced secondary voltage and current changes, the primary voltage still leading the induced secondary current by 90°. The resulting potentials applied to the diode will thus be different, the values changing with every frequency variation.

If the I/F output of a F.M. receiver is passed via a limiter into a discriminator the output will be an audio-frequency current similar in wave-form to the trans-mitter-modulating current.

Why is it necessary to include a Limiter Stage in Frequency-modulation receivers?
Draw a simple circuit diagram of one form of limiter and describe its operation.

The essence of the frequency-modulation (F.M.) system is that the carrier amplitude of the transmitted signal shall remain constant. It is thus necessary to ensure, at the receiver, that the signal supplied to the discriminator is free from all amplitude variations. The limiter is introduced between the final I/F amplifier and the discriminator to achieve this result.

Fig. 73 shows one form of limiter, popular in the U.S.A.
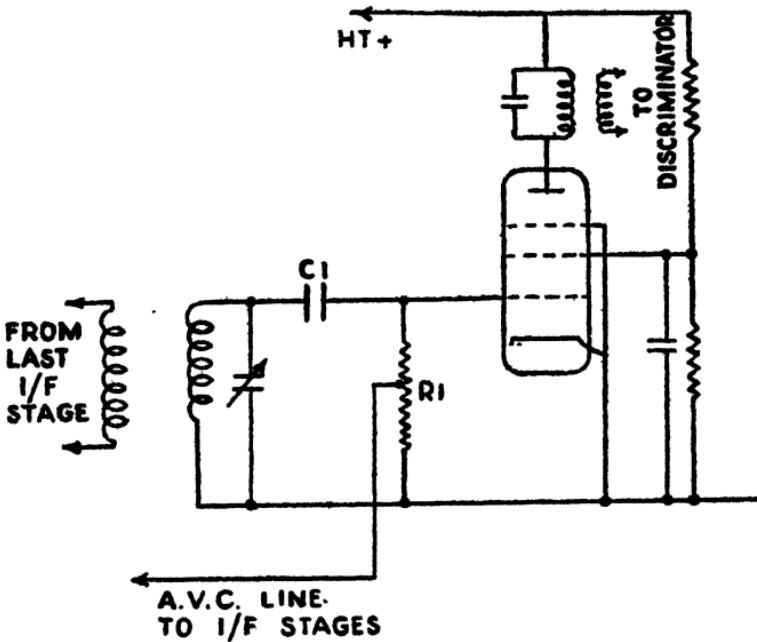
FIG. 73.

The I/F output is applied to the grid of the limiter valve via the small condenser $C1$. The limiter valve is a normal R/F pentode operating with low anode and screen voltages. Under these conditions the working point is well down on the mutual characteristic, cut-off occurring with $2\frac{1}{2}$ to 3 volts negative on the grid. Resistance $R1$ is a high value grid leak. It will be seen that the grid circuit simulates a cumulative or leaky grid detector; thus, as there is no standing bias on the grid, rectification occurs on the application of a signal. If the applied signal is sufficiently large to over-drive the valve, a condition will be reached under which anode current will flow only on the positive peaks.

The mutual characteristic of the limiter and a dia-grammatic represèntation of a burst òf amplitude interference, are shown in Fig. 74. Whatever the

ANODE CURRENT

O $-$ GRID VOLTS

AMPLITUDE INTERFERENCE

PASSED SUPPRESSED
BY LIMITER BY LIMITER

FIG 74.

applied signal amplitude, due to grid rectification, the upper carrier peaks are unable to exceed the cathode potential, thus any increase in the applied signal amplitude results in the mean grid voltage becoming more negative.

To ensure satisfactory operation of the limiter, several precautions must be taken. The limiter stage must be supplied with a signal sufficiently large to enable the limiting effect to reduce its amplitude to a predetermined level. The time constant of C_1 and R_1 must be sufficiently small to prevent amplitude variations in the limiter output due to slow recovery after grid rectification of a burst of interference, 2·5 microseconds is found to represent the upper limit.

A.V.C. is usually provided on the I/F stages, the control voltage being tapped off R_1 as shown. The amount of control afforded is reduced to a minimum so that the signal applied to the limiter will be as large as possible without overloading the preceding stages and also to obviate delays in limiter operation due to time constants of the A.V.C. circuits.

Draw a block schematic diagram showing the various stages of a wide-band frequency-modulated broadcast receiver. What is the usual range of intermediate frequencies used in this type of receiver?

Fig. 75 is a block schematic diagram showing the various stages of a F.M. receiver.

The stages up to the limiter stage are similar to the amplitude-modulated superhet receiver. The

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limiter, as its name suggests, limits the signal ampli-
tude to a predetermined value so that amplitude
variations are eliminated. The discriminator which is
perhaps the most important stage in the receiver,
translates changes in frequency of the received signal
into a current which is a reproduction of the original
modulating current. The majority of American F.M.
receivers have an intermediate frequency range of
4 to 5 Mc/s, many being standardised on a frequency
of 4·3 Mc/s.
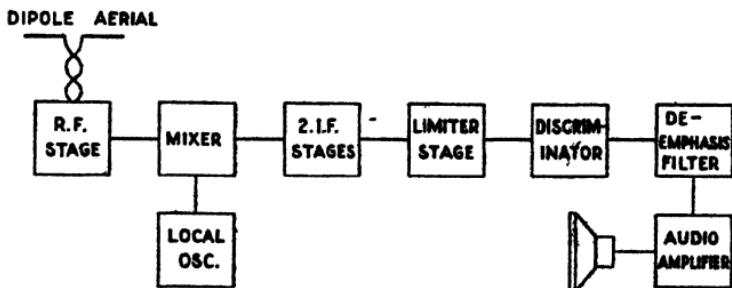
FIG. 75.

What is Frequency Modulation and how does it differ from Amplitude Modulation?
Why is Pre-emphasis of the higher audio frequencies of a F.M. wave desirable? Give simple diagrams of pre-emphasis and de-emphasis filters.

Frequency modulation is a method of impressing
intelligence, usually in the form of an audio-frequency
wave on a radio-frequency carrier. In an amplitude
modulated carrier, the audio-frequency modulation is
impressed on the R/F wave so that the amplitude
varies at the audio frequency. See Fig. 76 (B). The
amplitude of a F.M. carrier remains constant, but on
the commencement of modulation the frequency swings
above and below its mean value, the number of
"swings" depending on the frequency of the modulat-
ing signal. The extent of the swing, commonly called

(A) FREQUENCY MODULATED CARRIER.

(B) AMPLITUDE MODULATED CARRIER.
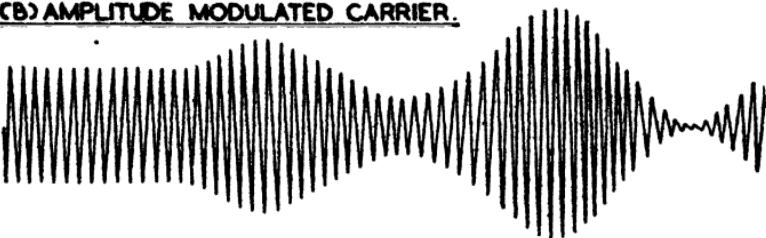
FIG. 76.

the deviation amplitude, is governed by the amplitude of the modulating wave.   See Fig. 76 (A).

It has been found that the distribution of interference over the audio-band width of a F.M. system is tri-angular which results in a steady progressive increase in the level at which noise is reproduced by the receiver, from the lower to the higher audio frequencies.   The upper audio frequencies are therefore masked by the interference, the lower still possessing a reasonable signal/noise ratio.   This state of affairs is worsened by the fact that with most modulating waves, the depth of modulation decreases as the frequency rises, but to achieve high fidelity reproduction retention of the upper audio frequencies is essential.   It is clear that to prevent this masking of the higher audio frequencies, some means of producing a reasonably even distribution of noise over the whole of the audio band, must be found.   This is achieved by accentuating or emphasising the upper audio frequencies before transmission and de-emphasising or restoring to normal at the receiver.   The accentuation and attenuation at the transmitter and receiver respectively is accom-

PRE-EMPHASIS FILTER
(a)

DE-EMPHASIS FILTER
(b)
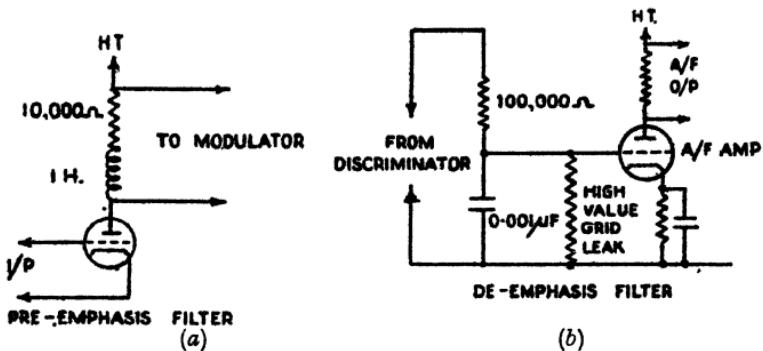
FIG. 77

plished by pre-emphasis and de-emphasis filters. See Figs. 77 (a) and (b).

The de-emphasis filter attenuates the interference in addition to the upper audio frequencies, so that while the intelligence is restored to its original form, the reproduction level of the interference is considerably reduced.

The American standard of pre-emphasis has been fixed using a series inductance resistance network having a time constant of 100 m.s. With this filter, the amplitude of the highest audio frequency (usually 15 Kc/s) is increased 10 times and interference above 5 Kc/s reproduced at an almost constant level. An improvement in the receiver response will thus result in a proportionate increase in noise and not, as without pre-emphasis, an increase equal to the square of the improvement.

Describe a good type of moving-coil loudspeaker, illustrating your answer with a simple diagram.

What will be the force on the moving coil at any instant?

Fig. 78 shows the essential components of a good type of moving-coil loudspeaker.

The moving part of the instrument consists of a stiff paper cylinder carrying the moving coil, rigidly attached by a paper flange to the cone of specially-prepared

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Field coil if not of permanent magnet type.

Paper flange.

Flexible suspension,

Direction of motion of coil and cone.

Moving coil.

Doped paper cone

Baffle
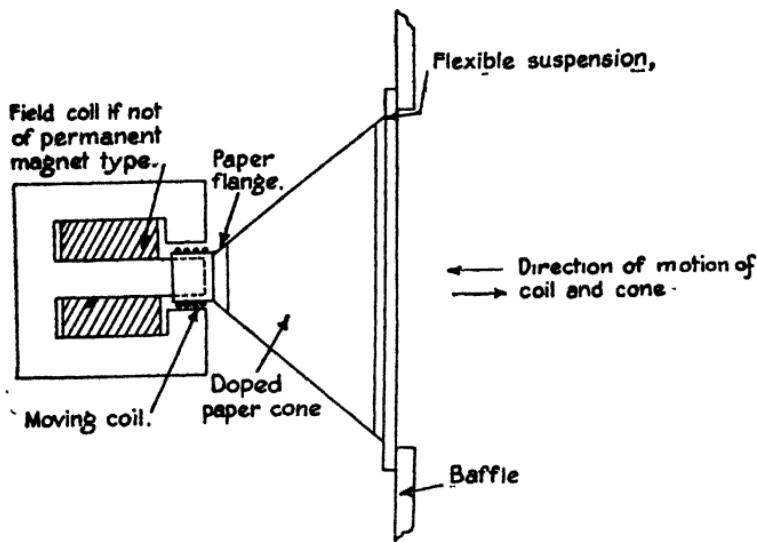
FIG. 78.

paper or stiff linen. The outer rim of the cone is secured to the main metal framework of the loud-speaker by a flexible suspension ring. The permanent magnet or the core of the electromagnet (if of the energised type), is shaped as shown to enable the cylinder carrying the moving coil to move in the narrow annular air gap.

The moving coil may consist of a few turns of fairly stout wire, or alternatively a large number of turns of fine wire, the former being the most usual. In the former case, optimum matching between the low impedance moving coil and the output stage feeding the instrument is obtained by means of a step-down transformer.

By means of a special flexible centring spider, or a light flexible corrugated disc cemented to both coil-carrying cylinder and main framework, the cylinder and coil are prevented from all movement except axially as indicated by the arrows and retained in their correct position in the air gap.

The permament magnet or core of the electro-

magnet core is rigidly fastened to the main loudspeaker framework.

The magnetic circuit consists of a central cylindrical po'e surrounded by an outer pole, the resulting magnetic field being radial across the narrow air gap.

To prevent low-frequency vibrations from merely displacing air from front to back of the cone, a baffle is fitted as shown, ensuring that the cone vibrations set up corresponding sound waves.

Suppose the strength of the magnetic field in the air gap, due to the permanent or electromagnet, is B, the length of wire on the moving coil is L and the current flowing through the coil at the instant under consideration is i. The force on the coil at that instant will be proportional to BLi.

CHAPTER V

TRANSMITTERS

Discuss the construction of transmitting valves having anode ratings up to 500 K.W.

The method of construction chosen for any particular valve depends on the anode rating required. Similar construction to that employed for receiving valves, although of course on a somewhat larger scale, may be used for valves dissipating up to 1·5 K.W. The envelope is of special heat-resisting glass and a molybdenum anode is used. External connection with the electrodes is effected via platinum substitute wires passing through seals in the envelope. Platinum substitute is a nickel-iron alloy thinly coated with copper, the copper being necessary as glass will not adhere directly to the alloy.

Transmitting valves dissipating between 1·5 and 20 K.W. may be enclosed in envelopes of silica or fused quartz, the latter having been almost entirely displaced by the former. The electrodes are similar in construction to those of the glass valve but a difficulty arises in the sealing of the connections into the silica envelope. Silica has an extremely small coefficient of expansion and in addition its softening temperature is very high (1500 C.). The only metal which has been found to adhere satisfactorily to silica is lead, and then only in the form of a plug melted into a thick-walled cylinder of silica. In practice molten lead is poured into tubes protruding from the envelope, internal and external connections being embedded in opposite ends of the plug. As the melting temperature of lead is low, it may be necessary to provide air-cooling for the seals.

The prime advantage of silica valves is that they

may be opened by means of a carborundum wheel to effect repairs to the electrode assembly, and then re-sealed with an oxy-hydrogen blow lamp. A damaged silica valve is thus almost as valuable as a new one, and should thus be treated with care.

To dissipate above 20 K.W. some form of anode cooling is essential to conduct away the heat generated during operation. In one of the common cooling systems, the anode is a copper cylinder surrounded by a brass water-jacket through which a continuous flow of water is maintained. The water-jacket is often electrically connected to the anode and its lugs form the external anode connection, in addition to providing a means of mounting the valve in the transmitter. Some types employ cylindrical anodes with one open end and others with both ends open. In the former type, the whole electrode assembly is suspended inside the anode from a glass cylinder sealed to the open end of the anode. When double-ended anodes are used, a glass cylinder is sealed to each end, part of the electrode assembly being mounted in each.

Valves of the above type may be constructed with anode ratings of up to 500 K.W.

Another high-power valve is the demountable type which is capable of being opened and repaired *in situ*, to this end the internal vacuum is maintained by continuously operating pumps. Demountable valves are manufactured with anode ratings of up to 500 K.W.

Describe one type of water-cooled high-power transmitting valve, illustrating your answer with a simple diagram.

Fig. 79 shows one type of water-cooled transmitting valve.

The anode of the valve forms an integral part of the envelope which is completed by glass end pieces supporting the remaining electrodes and their external connections.

The anode consists of a copper tube (for a 15 K.W.

GRID
CONNECTIONS

METAL END-CAP

GRID SEAL

GLASS END PIECE

ANODE SEAL

WATER OUTLET

COPPER ANODE

FIXING LUG, AND
ANODE CONNECTION

WATER INLET

ANODE SEAL

4 FILAMENT LEADS

GLASS END PIECE

4 FILAMENT SEALS

FILAMENT
CONNECTIONS

FIG. 79.

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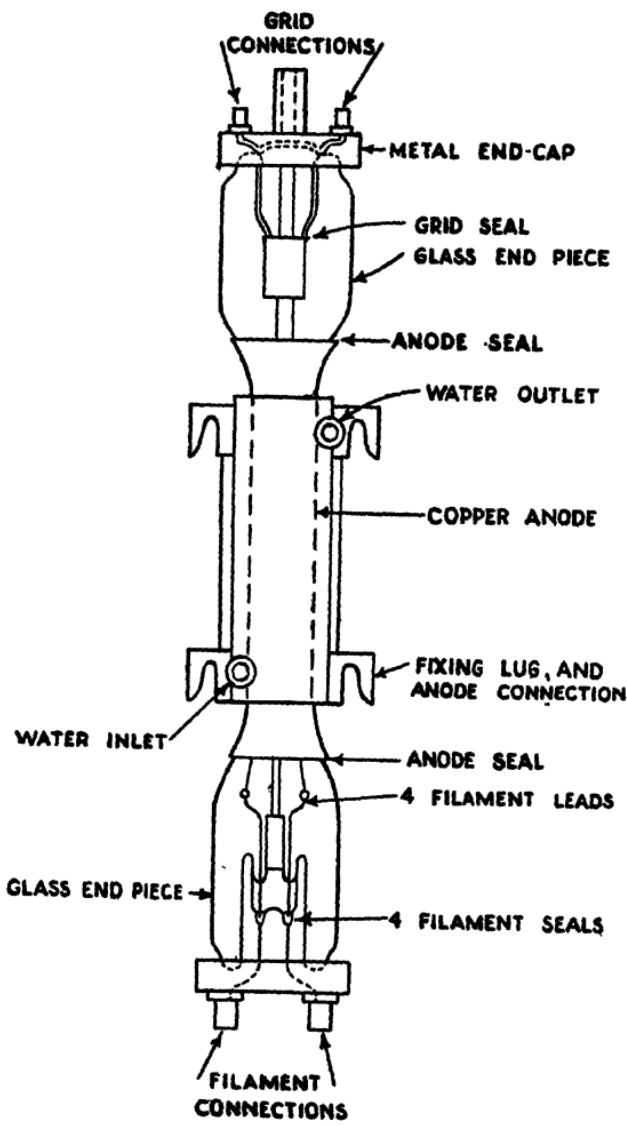
valve this will be approximately 2 inches in diameter) surrounded by a brass water-jacket, the spaces between the ends of the jacket and the anode being filled by copper rings sweated to both. Provision of inlet and outlet nipples on the water-jacket permits the maintenance of a continuous flow of water around the anode, the water conducting away the heat generated during operation of the valve. As the water-jacket is electrically connected to the anode (the jacket-fixing lugs form the external anode connection), care must be taken to use insulating pipes for connection of the water supply or to insulate the entire supply system.

Each end of the anode projecting beyond the water-jacket is flared and reduced to a razor-edge, a glass end-piece is inserted into the flare and the joint heated during application of pressure to form an air-tight seal. The filament and grid seals are made in exactly the same manner.

The filament assembly is supported by a molybdenum rod secured to an insulator in the lower glass end-piece. The molybdenum rod carries two filament hooks at its upper extremity on a small insulator and a single hook bound to its lower end. The "W" shaped tungsten filament is welded at its ends to copper filament leads and held under slight tension at the three apexes by the hooks. The filament leads pass through insulating bushes bound to the molybdenum rod below which they connect with four braided copper conductors, each of which passes through a separate seal in the envelope. The leads each terminate on an insulated metal stud mounted on the metal end-cap.

The grid assembly is supported by the upper glass end-piece. A copper rod carries a light molybdenum frame upon which is wound the grid, a helix of tungsten wire. The copper rod passes through a copper cap and supports the grid around the filament inside the anode, the copper cap being sealed.to the glass end-piece. The copper rod is connected to a flexible metallic strip in the metal end-cap which is in turn

connected to duplicate insulated studs which afford the external grid connection.

The insulating material used in the construction of high-power transmitting valves is generally steatite or one of its allied substances.

Describe without diagrams one method of cooling a high-power transmitting valve. Mention any precautions necessary.

One method of cooling a high-power transmitting valve is by forced water circulation.

In a valve designed for this type of cooling the anode forms part of the valve envelope and is in direct contact with the water circulating in the valve jacket. The valve is held in position in the jacket by means of a screw which engages in the anode end and tightens down the valve against the rubber sealing washer fitted between the anode and the top of the anode jacket. The water flow is governed by the rated anode dissipation and is determined by the makers.

The water is drawn from the storage tank by a centrifugal pump and passed through an artificial cooler. It then passes through a "water column" (the purpose of which will be discussed later) circulates round the anode and returns to the tank.

In some designs, the water also circulates through the hollow turns of the anode coil for additional cooling.

The artificial or air blast cooler consists of a large radiator and fan and serves to maintain the water at a satisfactory temperature, as for economy reasons it is desirable to use the same water indefinitely, allowing for normal evaporation.

Circuits are arranged which automatically switch off the power if the water supply fails or if the water temperature rises above the safe value. An alarm system is put into operation at the same time.

The purpose of the water column is to restrict current leakage from the anode to the earthed pipes

of the water system. The column usually takes the form of hose or porcelain tubing. This interposes between the anode and earth a column of water long enough to make its electrical resistance of the order of a few meg-ohms which, as previously stated, effectively prevents any leakage.

Distilled water is normally used both as an additional precaution and to prevent the silting up of the water system.

Anode deposits on this type of valve can be removed by placing the anode in a bath of dilute hydrochloric acid until chemical action between the anode and the solution ceases. The anode is then immersed in a second bath of dilute ammonia to neutralise the surplus acid. A final washing in clean water completes the process.

What do you understand by the " drive " circuit of a radio transmitter?
State three methods of transmitter frequency control.
Describe one of these methods.

The circuit in a wireless transmitter which supplies the constant frequency R/F oscillations is termed the " drive " circuit.

Three methods of transmitter frequency control are by means of:

    (1) The Master Oscillator.
    (2) The Tuning Fork Controlled Oscillator.
    (3) The Piezo-electric Crystal Controlled Oscillator.
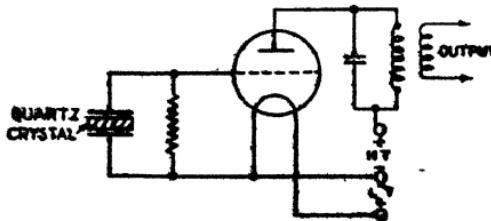

FIG. 80.

The elements of a simple Crystal Controlled Oscillator circuit are shown in Fig. 80.

Application of the power supplies causes anode current to flow producing a r.D. across the Quartz Crystal which commences to vibrate at its natural frequency. These vibrations are produced in the anode circuit by the anode current controlling effect of the grid, and if the anode circuit be tuned to approximately the natural frequency of the crystal, the amplitude of the oscillations will be greatly increased. A small portion of the anode circuit oscillation is fed back to the grid circuit via the anode/grid capacity of the valve and as this offsets crystal losses, continuous oscillation results.

The grid leak connected across the crystal between grid and filament (or cathode) maintains the grid bias at the correct operating value.

Theoretically maximum output will be obtained with the anode circuit tuned to a frequency slightly above that of the crystal, since under these conditions the input resistance of the valve will be negative due to Miller effect. However, in practice it is usual to adjust the anode circuit to give the best results, since variations of the anode tune alters the wave-form and amplitude of the R/F output.

Why is it necessary to neutralise triode amplifier stages in radio transmitters?

How would the final triode push-pull stage of a medium-power short-wave transmitter be neutralised? Illustrate your answer with a diagram.

When a triode is utilised as an amplifier, the voltage developed in the anode circuit causes current to flow in that circuit but in addition current flows through the anode/grid capacitance of the valve, via the external grid circuit to the cathode. The grid current thus consists of both the normal current due to the inherent impedance of the grid circuit (usually negligible) and,

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in addition, the feed-back current, frequently of a considerable magnitude.

It may be considered that an additional impedance has been connected across the grid cathode circuit, the type of impedance depending on the phase of the feed-back current, which is itself determined by the anode circuit load.

The reflected grid impedance produced by various anode loads will conform to the following table:

(a) Anode load preponderantly Resistive—Reflected grid impedance Capacitative.

(b) Anode load preponderantly Capacitative—Reflected grid impedance Resistive.

(c) Anode load preponderantly Inductive—Reflected grid impedance a Negative Resistance.

In the third case the feed-back current will be in such a direction as to augment the initial grid voltage, in some cases throwing the valve into a state of self-oscillation.

The method of overcoming this problem of instability caused by anode/grid feed-back, is by the use of neutralising condensers.

The neutralising condenser (variable) is connected between the anode and a point in the grid circuit opposite in phase to the grid itself. The feed-back potential between grid and cathode set up by this artificial feed-back current will thus be opposite in phase to that produced by the inter-electrode feed-back. Adjustment of the artificial feed-back so that it is the same value as (but opposite in phase to) the natural feed-back, by means of the neutralising condenser, will result in the stabilisation of the circuit.

Fig. 81 shows the push-pull stage of a medium power short-wave transmitter. Neutralising is effected by means of the two variable neutralising condensers NC. It will be seen that the anode of each valve is connected via its relative neutralising condenser to a point opposite in phase to the potential of its own grid, i.e. the grid of the other triode.
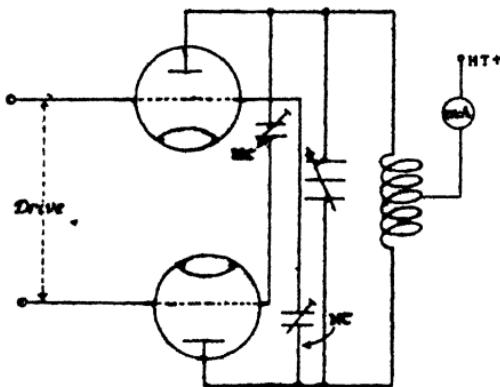
FIG. 81.

As the whole circuit is perfectly symmetrical, with respect to earth, perfect neutralising can be achieved, even at operating frequencies of 14 Mc/s.

What is the function of a microphone in Radio Telephony?
Enumerate three types of microphone involving widely different principles. State briefly what these principles are.

The microphone is the instrument necessary for the conversion of sound waves into complex, variable electric currents suitable for the modulation of a carrier wave.

Three different types of microphone are:

    (*a*) Carbon microphone.
    (*b*) Moving coil microphone.
    (*c*) Crystal or Piezo-electric microphone.

(*a*) The carbon microphone depends for its operation on the property possessed by carbon granules whereby the electrical resistance of a mass of granules situated between two electrodes, varies with the mechanical pressure exerted on them.

One common form of carbon microphone consists of a light conical metal diaphragm fastened at its apex to a circular carbon electrode. The gap between this

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moving electrode and a fixed carbon electrode is almost filled with fine carbon granules, retained in place by an insulating cylinder, the whole being assembled in a light metal container.

Sound waves striking the conical diaphragm set it in vibration in accordance with their frequency and amplitude, resulting in a corresponding variation in electrical resistance which may be used to control a small D.C. current passed through the instrument.

(b) The moving coil microphone operates on exactly the same principle as the moving coil loudspeaker except that the process is reversed. A small coil of wire wound on an extension of a light conical diaphragm is placed in the radial field of a permanent magnet. Movements of the coil resulting from sound waves striking the diaphragm produce corresponding currents in the coil, which may be amplified as required. The whole instrument is very much smaller than an average moving coil loudspeaker.

(c) The crystal microphone utilises the piezo-electric properties of certain crystals, the crystal most frequently used for this purpose being Rochelle Salt, chosen by reason of its extreme sensitivity.

The most common form of crystal microphone consists of two crystal slices usually of square section, cemented back to back and supported at their ends so that they may be bent up and down like a beam similarly supported. A light diaphragm conveys vibrations set up by sound waves to the centre of the crystal slice by means of a spindle. As the crystal is moved up and down by the diaphragm vibrations, a varying piezo-electric potential is produced across the crystal faces. This potential will cause corresponding piezo-electric currents to flow in an external circuit, the currents may be amplified in the normal way.

Enumerate in table form the relative advantages and disadvantages of the following types of microphone:

　　　(a) Carbon;

(b) *Moving Coil;*

(c) *Crystal.*

What type of microphone would you choose for each of the following purposes?   Give brief reasons for your choice:

(1) *An outside broadcast from a noisy situation;*

(2) *The studio broadcast of a talk;*

(3) *For use with an announcement system requiring only commercial quality speech.*

Type.	Advantages.	Disadvantages.
Carbon	Large output. Relatively inexpensive. Reasonably robust. Very sensitive.	Polarising potential of from 4–10 volts required. Continuous background hiss. Possesses optimum working position (almost vertical). Extremely sensitive to extraneous noises. Carbon granules "pack," resulting in variable performance. Very "peaky" frequency response. Easily overloaded by loud noises.
Moving Coil.	No polarising potential required. Very robust. Constant performance. Free from overloading.	Relatively insensitive. Fairly small output. Very expensive.

Type.	Advantages.	Disadvantages.
Moving Coil.	Free from packing. Insensitive to external vibrations. Good frequency response. May be used in any position.	
Crystal.	Large output. No polarising potential necessary. Good frequency response, especially to speech. Free from packing. Can be used in any position. May be directly connected to the grid of an amplifier. Medium price.	Must be carefully handled to prevent damage to crystals.

(1) A moving coil microphone would be very suitable for this purpose since it is relatively insensitive, may be used in any position, and is free from overloading.

(2) Since the microphone is stationary and good response to speech is desired, a crystal instrument would meet the case.

(3) As only medium quality speech is required, a carbon microphone could be conveniently utilised, precautions to prevent overloading would be necessary.

State the essentials of one method whereby a radio transmitter can be modulated and carefully explain its working.

The system in most general use involves the modulation of the aerial current in accordance with the current variations produced by speech in the microphone circuit. The aerial current is proportional to the high frequency component of the anode current of the final radio-frequency amplifier and this in its turn can be made very nearly proportional to the voltage applied to the anode circuit of the radio-frequency stage.

The outlines of a circuit for accomplishing this are shown in the Fig. 82.

$V1$ is a high-frequency amplifier coupled to its tuned circuit and the aerial system. A single valve is shown but if necessary a balanced push-pull arrangement may be used. $V2$ is the modulating valve. $L1$ is a radio-frequency choke which confines the high-frequency currents to the radio-frequency amplifier and its output circuit; its impedance to audio frequencies is negligible The reactance of the condenser C is large at audio frequencies but small at the radio frequencies. $L2$ is an iron-cored choke and its reactance is high over the whole audio-frequency range.

A constant radio-frequency drive is applied to the grid of $V1$ which is operated in the class C condition. Audio-frequency drive corresponding to the current in the microphone circuit (not shown) is applied to the modulating valve $V2$. $V2$ is essentially an audio-frequency amplifier and its load impedance is that provided by the valve $V1$, since the reactance of $L2$ and C are high. The audio-frequency voltages applied to the grid of $V2$ therefore produce audio-frequency voltages on its anode and across its load impedance. $V1$ thus operates as an amplifier in which the anode supply voltage is made to vary about a mean value in accordance with the signals from the microphone circuit. If sufficient drive is applied to the grid of $V1$ and the radio-frequency output circuit adjusted to
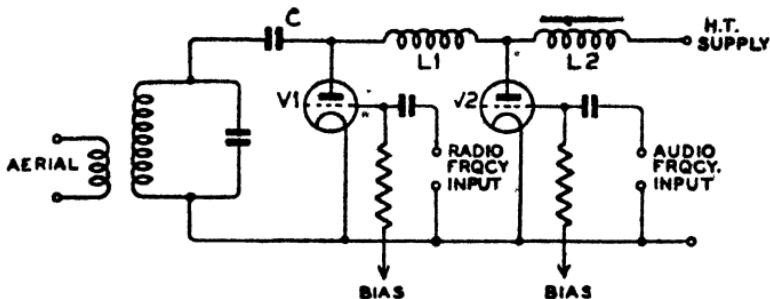
FIG. 82.

give the correct load impedance, the output from V_1 will be very nearly proportional to the anode voltage.

Since the valves V_1 and V_2 must have the same mean anode potential it follows that the percentage modulation will be determined by the ratio of the peak audio-frequency potential to the mean D.C. potential on the anode of V_2. If the distortion in the output circuit is not to be excessive then this ratio must not approach too closely to unity and thus the maximum percentage modulation is limited.

A radio telephone transmitter in the unmodulated state has a carrier output of 12 Kilowatts and can be modulated to a maximum of 80% by single frequency tone before overloading. If a limit of 50% is imposed, to what value can the carrier power be increased?

It is assumed that overloading occurs when the maximum value of oscillatory voltage exceeds the steady anode potential upon which it is superimposed in the final stage of the transmitter. Let the steady voltage be V and the original unmodulated carrier maximum voltage be V_m.

$$\text{Then } 1{\cdot}8 \; V_m = V$$

Furthermore, if V_1 is the maximum value of the unmodulated carrier voltage when a limit of 50 per cent modulation is imposed, then

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$$1 \cdot 5 \ V_1 = V$$
$$\text{Thus } V_1 = \frac{1 \cdot 8 \ V_m}{1 \cdot 5} = 1 \cdot 2 \ V_m$$

Furthermore, the carrier powers vary as the squares of the carrier voltages.

Thus the carrier power can be increased to
$$12 \times 1 \cdot 2^2 = 17 \cdot 28 \text{ Kilowatts.}$$

What maintenance duties should be carried out to ensure the efficient running of a transmitting station?

In order to obtain the highest operational efficiency the station engineer should study the staff at his disposal, the apparatus to be serviced and type of building.

One of the first considerations in effective maintenance is a dust-free transmitting hall. Wherever possible the floors should be covered with linoleum which should be kept polished. All exposed concrete floor or plinths should be treated with a dust-resisting preparation. Where a fair amount of heat is dissipated in a hall it is desirable to fit a number of exhaust fans in the roof.

The technical staff should be allocated to watches in such a manner that a small number are available for day duties as "station mechanics" to carry out the routine maintenance of transmitters.

By ensuring that an experienced member of the staff is always in charge of the maintenance team, and changing its members on a roster system, all technical personnel can be brought up to a high standard of efficiency.

Where the transmitters are in service on a twenty-four-hour basis arrangements should be made to free each transmitter once per month for a period of four to eight hours dependant on its size and the number of units involved. Where possible, the transmitter undergoing maintenance should be replaced by the station reserve.

A study should be made of each type of transmitter

and a maintenance schedule drawn up indicating the main points for attention. It is desirable to remove all side panels and thoroughly clean all parts of the transmitter, using a vacuum cleaner where possible. All bearings, universal joints, mechanical parts, etc., should be cleaned and lubricated.

Gate switches and safety devices should be inspected, all relays checked and contacts cleaned. The station workshop should be equipped with a linen buffing wheel and Tripoli preparation for contact burnishing. The bearings of all electric motors and pump machinery should be inspected and lubricated according to the makers' instructions. It is important to note that over-greasing can be as harmful as lack of grease. Oil transformers should be inspected and topped up where necessary.

If the maintenance party are trained as a team all the salient points can be covered in a reasonable time. The latter end of the period should be reserved for test purposes. The transmitter should be set up on one of the standard test frequencies (using an artificial load if possible) and all meter readings compared with the original test figures obtained by the manufacturers, or on installation. Reference should be made to the valve logs recording valve life and adjustments made where necessary to the filaments and power supplies After the transmitter has gone back into service the Routine Maintenance Chart should be signed up by the engineer carrying out the work.

Why is monitoring equipment necessary at a transmitting station? Mention one form of monitoring equipment and describe how it works.

The monitoring or Signal Checking Equipment at a transmitting station enables quick investigation of transmission complaints and provides a means for periodical checks to be made on the transmitters in service.

One effective method when double current keying

is used is by arranging to record on a tape both the input and output signals by means of a double undulator.

Using a jacking system a relay is plugged in parallel with the keying relay of the transmitter under examination, without interference with the transmission. The additional relay controls an undulator which records the incoming signal on one half of the tape.

A small amplifier is coupled to the output circuit of the transmitter and picks up the transmitted signal. The resultant R/F is fed back to the checking equipment and passed to a bridge amplifier which converts it back to the conventional double current signal and amplifies it to a level sufficient to work the second undulator which records the transmitted signal on the other half of the tape.

Thus a direct comparison of input and output signals can be made and any faults localised to either the incoming D.C. signal or the transmitter.

What is Piezo-Electric effect?
Write a short essay on Piezo-Electric crystals.

Piezo-Electric effect is the term applied to the peculiar property possessed by slices of certain crystals (i.e. Rochelle Salt, Tourmaline and Quartz). This property is that if subjected to mechanical pressure, a P.D. is developed across the crystal, application of tension producing a P.D. in the opposite direction. Similarly, application of a P.D. across the crystal in one direction causes mechanical expansion, in the other, mechanical contraction. The direction of these mechanical variations being at right angles to the electric field.

Piezo-electric crystals in common use are normally cut from quartz, the "mother quartz" occurring naturally in Brazil and Madagascar. Quartz is the most common material employed as its mechanical strength, durability and cost compare very favourably with other piezo-electric substances.

A natural crystal of quartz is roughly hexagonal-

sided with irregular ends. It possesses three sets of axes; the optical, vertical or Z axis running parallel with the sides, three electrical or X axes across the corners of the hexagon and three Y axes at right angles to both the sides of the hexagon and the X axes.

The operating or natural frequency of a piezo-electric crystal depends upon the manner in which the slice is cut from the whole crystal and upon its thickness.

There are two very common "cuts," namely the X and Y cuts.

X cut crystals are cut parallel to the Z axis with the thickness parallel to the X axis and the width parallel to the Y axis.

Y cut crystals are cut at an angle of 30° from the Z axis, the thickness and width being parallel to the Y and X axes respectively.

The natural frequency of an X cut quartz crystal may be determined by the following formula:

$$f = \frac{2 \cdot 860}{t} \text{ Kc/s.}$$

Where t is the thickness of the plate in mm.

The natural frequency of a crystal varies with temperature, an X cut crystal having a negative temperature coefficient in the order of 20 parts in 1,000,000 per degree Centigrade and a Y cut crystal a positive coefficient of the same order.

The above suggests that by careful cutting, crystals with zero temperature coefficients might be obtained. This has been achieved, the crystals being known as constant temperature or A.T. cut.

How are Quartz Crystals mounted for use in wireless transmitters?
Enumerate the precautions necessary to ensure that the output of a crystal controlled oscillator will be of a high standard of accuracy.

The frequency of oscillation of a quartz crystal varies with temperature, thus one of the essential properties of a good crystal holder should be its capability to

maintain the crystal at the same temperature during operation.

There are several types of crystal holder.

(1) The open type.
(2) The enclosed type.
(3) The enclosed, temperature-controlled type.

In each case the crystal is placed between two accurately plane metal surfaces, usually of brass.

The open type is often used in amateur transmitters, but is seldom found in professional equipment. The crystal lies on one metal surface, the other ground on a "floating" electrode, is placed on the crystal. No gap adjustment is afforded and connection with the upper plate is made by means of a flexible pigtail.

The second, enclosed type, consists of two large masses of metal separated by an insulating ring. In this case the two surfaces are accurately parallel as well as plane, the air gap between the plates being adjustable by means of a micrometer screw associated with the upper plate. The large mass of metal will, to a great extent, prevent crystal temperature changes, the metal acting as a heat reservoir.

The most effective crystal holder is the temperature-controlled type, in which the crystal and plates are enclosed in a chamber, the temperature of which is either thermostatically controlled or maintained at a value higher than the highest ambient temperature which might be encountered.

The following precautions are necessary if the output of a crystal oscillator is to be maintained at a high standard:

(1) The crystal should have a natural frequency of from 3 to 5 Mc/s and be cut to give a minimum temperature coefficient and be free from multiple frequencies of vibration.

(2) The crystal, and, if necessary, the entire oscillator circuit, should be enclosed in a temperature-controlled chamber.

(3) The crystal itself should never be handled as the

presence of wax, grease or scratches on the crystal result in erratic operation.

(4) The oscillations should be constant and independent of the transmitter output.

(5) The oscillator power supplies must be constant.

For what frequencies are Quartz Crystals most suitable?
How may crystal-controlled oscillations of much higher frequency be obtained?

The natural frequency of a crystal varies inversely with its physical thickness, it therefore follows that the higher the frequency required, the thinner must the crystal plate be ground.

It is possible to obtain quartz crystals having natural frequencies of from 25 Kc/s to 4 Mc/s by comparatively simple means.

Quartz crystals having natural frequencies between 25 Kc/s and 4 Mc/s may be cut with relatively little difficulty. By means of the most modern crystal cutting and grinding machines natural frequencies as high as 20 Mc/s have been obtained, although it will be appreciated that these crystals must of necessity be extremely fragile.

In practice it is more usual, when frequencies above 6 or 7 Mc/s are required, to utilise a crystal cut with a natural frequency of between 3 and 5 Mc/s in conjunction with a frequency multiplier.

The oscillator valve controlled by the crystal is caused to work at a non-linear point on its characteristic curve, a long range of harmonics or more correctly overtones being introduced into the output. The required harmonic may be selected by suitable tuned circuits and amplified as required by succeeding stages of power amplification.

Frequency doubling is a particular case of the general process of frequency multiplication, one of the most common frequency doubling circuits consists of a push-pull arrangement in which both valves are biased

to cut-off. The input circuit is tuned to the natural frequency of the crystal, the output circuit to twice this frequency.

Write a short account of three applications of the quartz crystal.

Three quartz crystal applications are:
  (1) As a frequency control for wireless trans-
      mitters.
  (2) As a resonator element in electric wave filters.
  (3) As a fixed frequency oscillator.

(1) The great increase in the number of radio trans-mitters which must be accommodated in the spectrum has necessitated some form of transmitting frequency control. The quartz crystal is widely used for this purpose for transmitters operating on frequencies above 50 Kc/s., the very high carrier frequencies being obtained by frequency multiplication.

(2) Another use for the quartz crystal is as a resonator element—in the electric wave filter, and in general a Q value of 10,000, which is normally sufficient for the purpose, can be obtained in a very simple type of holder.

Filters employing crystal-resonator elements have been designed which approach very near to the ideal, and the design of a number of the multi-channel tele-phone systems now in commercial use is based on the quartz crystal filter.

(3) The bridge-stabilised oscillator, comprising a Wheatstone Bridge and an amplifier, is likely to find application where the highest order of frequency stability is required. The crystal must be free from double-frequency effects over its temperature range. Because of the limited power which the crystal oscil-lator can handle safely, and owing to the extreme fragility of the higher-frequency plates, it is usual to employ a plate frequency below 10,000 Kc/s. in a low-power drive, and to achieve the required carrier power and frequency with frequency-doubling amplifiers.

The quartz crystal can also be used to advantage in receivers where high stability on a particular fixed frequency is desired.

Give two methods of carrying out frequency modulation. What are the advantages claimed by frequency modulation over amplitude modulation?

The two methods of carrying out frequency modulation are:

(1) To vary the carrier wave by a given percentage *at a rate* depending upon the modulation frequency required.

(2) By varying the carrier frequency an amount equal to the modulation frequency desired.

The advantages of frequency modulation are:

(1) An increased number of channels can be obtained from a given waveband. A channel width of 250 Kc/s. for normal broadcast services has been suggested, this would give 40 channels if a 10 Mc/s. band-width were allocated to modulated frequency transmissions.

(2) A marked improvement could be expected in the signal-to-noise ratio on local transmissions.

(3) Reduction in transmitting power for distances up to 100 miles compared with amplitude-modulated transmissions.

(4) Frequency modulation is less affected by poor atmospheric conditions than amplitude modulation.

(a) ***Name two types of Frequency Modulator circuits, and explain with the aid of a diagram the operation of one.***

(b) ***State briefly what you consider to be one of the most important considerations in the design of a frequency-modulated transmitter.***

(1) The Armstrong Modulator Circuit.

(2) The Variable Reactance Valve Modulator Circuit.
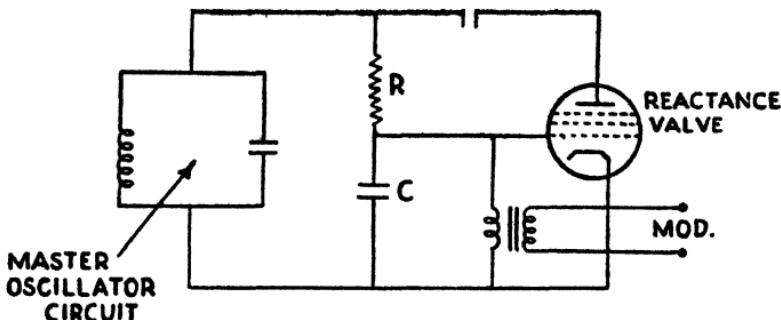
FIG. 83.

The Variable Reactance Valve Modulator Circuit.

Fig. 83 shows the basic circuit of the reactance valve modulator.

The tuned Master Oscillator circuit has a resistance *R* and a condenser *C* connected in parallel with it as shown. *The value of the resistance R* is designed to be very high in comparison with the impedance of the condenser *C* with the result that the voltage across this condenser lags $90°$ behind that across the tuned circuit. It will be seen from Fig. 83 that this lagging voltage is applied to the control grid of the reactance valve with the result that the current through the valve will lag $90°$ behind that in the tuned circuit. As the valve fulfils all the necessary conditions, it can be regarded as an inductance shunted across the tuned oscillatory circuit. Furthermore its "inductance" value can be varied by altering the value of the anode current flowing. An audio signal applied to the grid of the valve will therefore vary the anode current flowing and hence vary the inductance across the tuned oscillator circuit. It follows, therefore, that the master oscillator is frequency modulated as a result of the signals applied to the grid of the reactance valve.

(*b*) One of the most important considerations in the design of a frequency-modulated transmitter is the *frequency stability of the carrier wave.* In America the Federal Communications Commission consider

this to be so important that they have laid down that the carrier must remain on its allotted frequency to within ± 2 Kc/s.

How is " frequency drift " corrected in a Frequency-modulation Transmitter using variable reactance modulation?

Frequency drift correction is achieved by means of a frequency control circuit associated with the modulator as shown in Fig. 84.
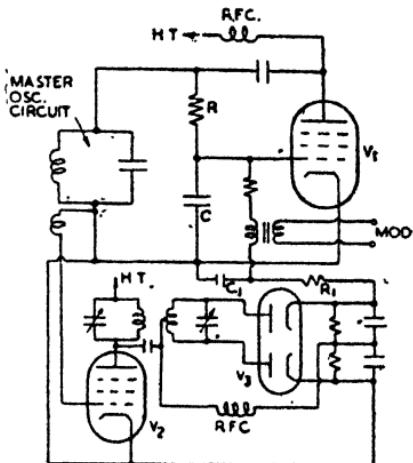

FIG. 84.

Stabilisation is produced by supplying part of the master oscillator's output to amplifier valve V_1. The output from the audio-frequency discriminator in the anode circuit of this valve is arranged so that the variable reactance valve bias is increased when the valve presents too low an inductive shunt across the oscillator circuit.

An increase in the bias supplied results in the reactance valve applying a smaller effective shunt inductance and so allowing the master oscillator frequency to fall. Should the oscillator frequency be low the discriminator will supply the reactance valve with less bias, so causing the oscillator frequency to increase.

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Explain with the aid of a simple block schematic diagram the action of the various stages of an Armstrong type F.M. transmitter. Mention the merits and demerits of this type of transmitter.
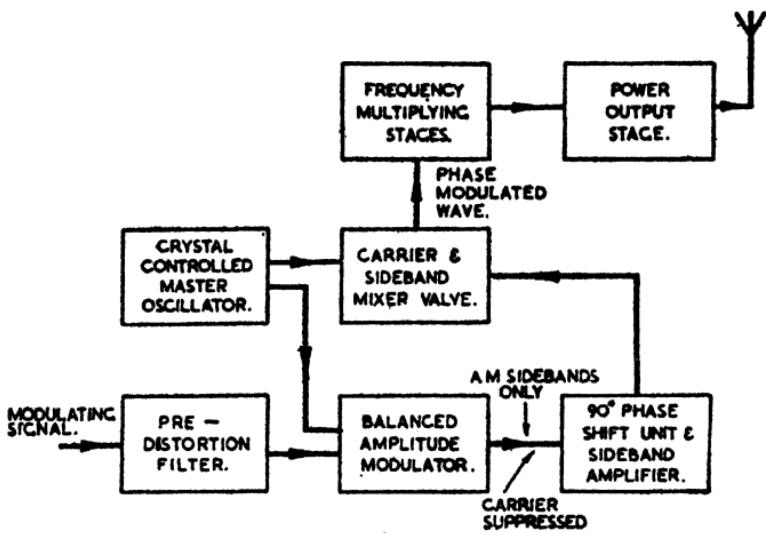

FIG. 85.

A simplified block schematic diagram of Armstrong's frequency modulation transmitter is shown in Fig. 85.

The output from a crystal-controlled oscillator is fed to two circuits; the carrier side-band mixer valve circuit and the balanced amplitude modulator circuit. The audio signal is passed through the pre-distortion filter which has a rising attenuation characteristic. The carrier is cancelled out across the output transformer on the anode circuit of these two valves, so leaving the amplitude modulation sidebands only. By feeding these sidebands through a small condenser they are given a 90° phase shift. The output from the master oscillator is combined with these phase-shifted sidebands on the anode of a mixer valve.

The effect of combining a carrier with amplitude modulation sidebands which have been shifted in phase by 90°, is shown in Fig. 86. These Vector

diagrams show that the result is phase modulation of the carriers. After the audio input has been corrected to provide a frequency modulation deviation characteristic which is level over the audio band Armstrong's modulator produces a maximum frequency modulation of some 20 to 25 cycles. This frequency modulation is then multiplied in the penultimate stage. For example—if the transmitter is to operate at a maximum deviation of 75 Kc/s. these frequency changes (20 to to 25 cycles) must be multiplied some 3,000 times.

The chief merit of the Armstrong transmitter is that, being based on a Crystal controlled oscillator, it has a higher inherent frequency stability than any other type of frequency modulator.

The principal objections raised against Armstrong's transmitter is the large amount of frequency multiplication required.
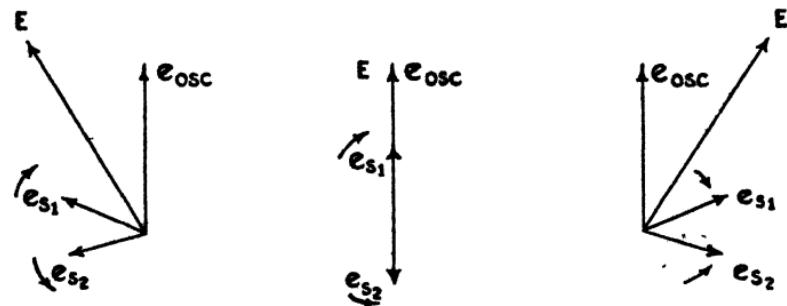
e_{OSC} = OSCILLATOR OUTPUT VOLTAGE

e_{S_1} & e_{S_2} = AMP. MODULATION SIDEBANDS PHASE SHIFTED 90°

E = PHASED MODULATED WAVEFORM

E = phase modulated wave-form.
e_{osc} = Oscillator output voltage.
e_{s1} and e_{s2} = Amplitude modulation sidebands, phase shifted by 90°.

FIG. 86.

CHAPTER VI

POWER SUPPLIES FOR RADIO EQUIPMENT

What is a metal rectifier? How may metal rectifiers be used to obtain a high-tension D.C. supply from A.C. mains?

A metal rectifier is one of the many "single path" devices which may be used to procure a direct current from one of the alternating variety. It is actually a more permanent form of crystal detector, the crystal and "catswhisker" or crystal couple being replaced by discs of metallic copper and copper oxide.

FIG. 87.

SPACES LEFT BETWEEN ELEMENTS FOR CLARITY
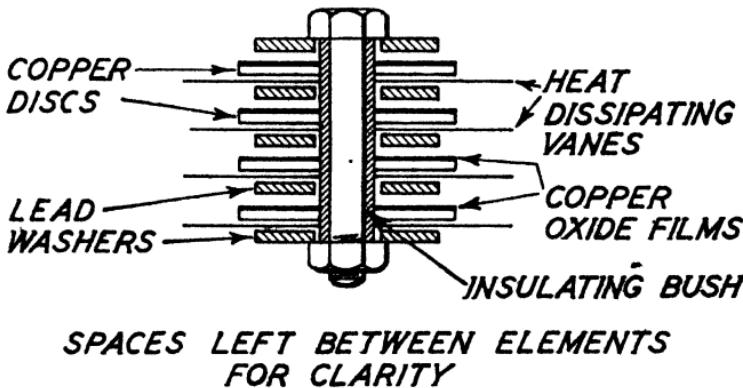
The rectifier is usually made up of copper discs, one side of each having been subjected to a special heat treatment which produces a thin layer of copper oxide. A number of these discs are rigidly bolted together with lead washers as spacers, and large metal fins to dissipate the heat generated during use.

A voltage applied in the direction from oxide to

(a)

(b)

Direction of Electronic Current

(c)
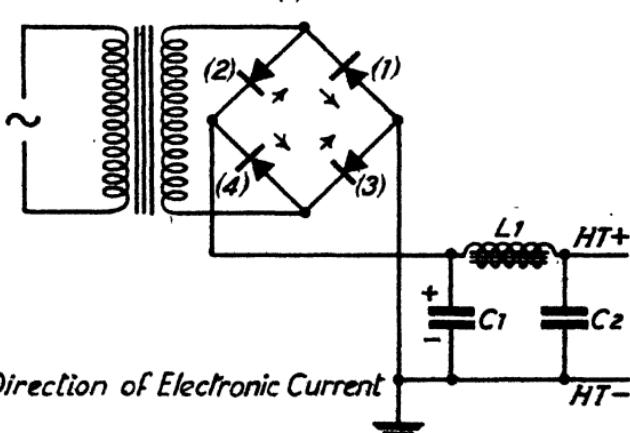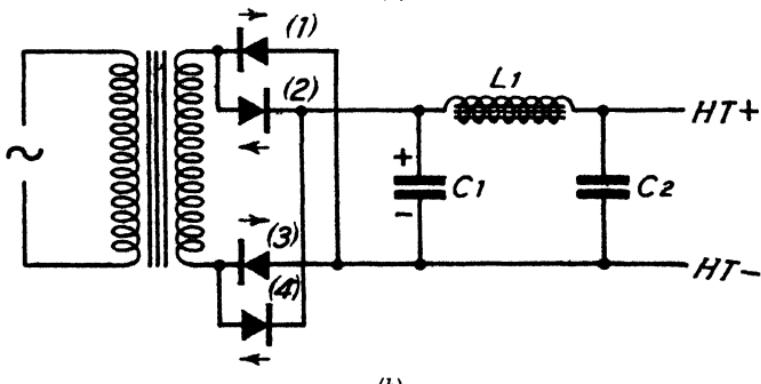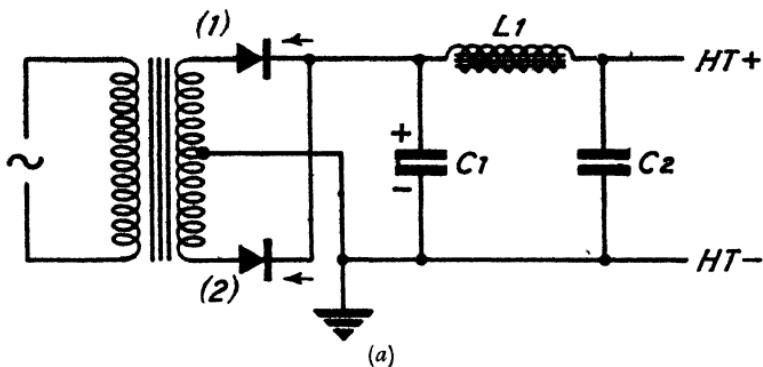
Fig. 88.

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metal produces a much greater current than a similar potential applied in the metal-oxide direction (Fig. 87).

There are several methods of employing metal rectifiers to obtain high-tension current for the operation of wireless apparatus.

Three of these methods are illustrated in Fig. 88.

Fig. 88 (a) of above diagram shows a metal rectifier unit requiring a centre-tapped mains transformer. Half of the available alternating secondary potential is applied across each rectifier element, rectifier (1) providing a conducting path during one half-cycle, rectifier (2) during the succeeding half-cycle. It will be seen that reservoir condenser $C1$ receives a charge twice during each cycle of applied alternating voltage, and that the arrangement corresponds exactly to a full wave thermionic valve rectifier.

Figs. 88 (b) and (c) illustrate two very popular methods of connecting metal rectifiers. The rectifiers are used in pairs, the necessity for a centre-tapped transformer being obviated.

During one half-cycle of applied alternating voltage, rectifiers (1) and (4) are conducting, rectifiers (2) and (3) during the succeeding half-cycle. Reservoir condenser $C1$ thus receives two charges as shown for each cycle of applied alternating potential.

The D.C. output voltage of these rectifier units is twice that of the rectifier illustrated in Fig. 88 (a) for a similar secondary voltage, since the whole of the secondary alternating voltage is utilised. In short, Figs. 88 (b) and (c) are full-wave rectifiers in the truest sense. Application of this term to double-diode thermionic valve rectifiers and metal rectifier units of the type shown in Fig. 88 (a) is not strictly correct.

What is a voltage doubler? How does it operate and what are its uses?

A voltage doubler is a rectifier unit usually utilising metal rectifiers, but thermionic valves may be readily substituted, which provides a D.C. output
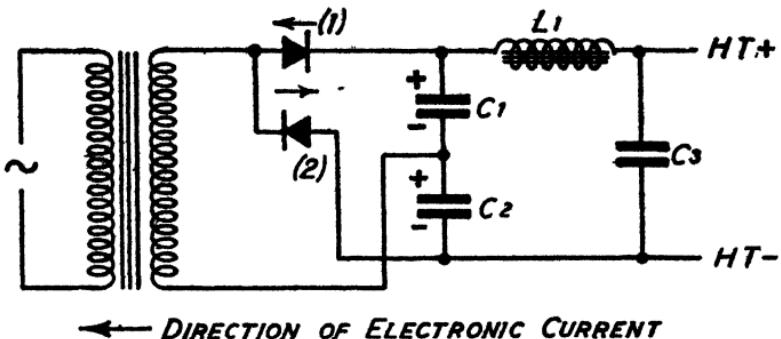
FIG. 89.

voltage of approximately twice the alternating potential developed across the secondary winding of the mains transformer.

A typical voltage doubling circuit is illustrated in Fig. 89.

Rectifiers (1) and (2) are connected in opposite directions to the same secondary terminal of the mains transformer, each functioning as a half-wave rectifier during alternate half-cycles of the alternating secondary voltage.

When rectifier (1) conducts, condenser C_1 is charged as shown in the sketch, similarly condenser C_2 when rectifier (2) is in a conducting condition.

The whole of the secondary voltage is applied across each rectifier in turn, and it will be seen that the D.C. output potentials developed across condensers C_1 and C_2 are additive, as the condensers are connected in series.

The combined D.C. output potential is thus approximately equal to twice the transformer secondary voltage.

An arrangement of this nature is not usually used when a high current output is required, but is excellent in cases where a high voltage at a few milliamperes is all that is necessary.

By taking special insulation precautions voltages in the order of 500,000 may be easily obtained.

Voltage doublers are frequently used to provide high-tension supplies for the following apparatus:

    ·   (1) Cathode Ray Tubes.

       (2) X-ray Equipment.

Describe the operation of a full-wave thermionic valve rectifier.

Derive a simple formula for the percentage ripple in the output of such a rectifier unit.
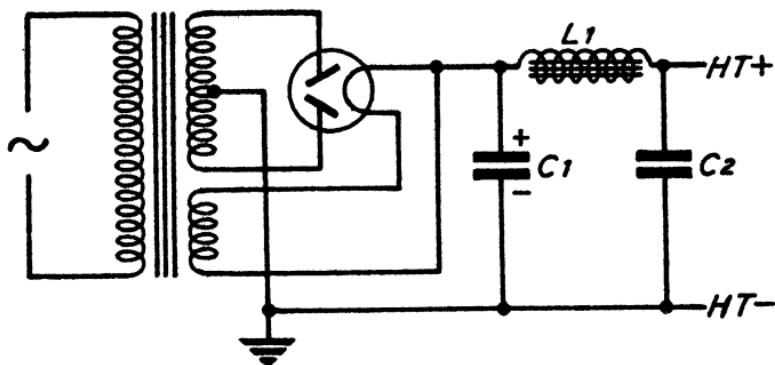
FIG. 90.

The full-wave rectifier shown in Fig. 90 utilises a double diode rectifier valve, the two separate diodes being housed in the same envelope.

The transformer secondary H.T. winding is centre-tapped, the centre point being connected to earth and the two outer ends of the winding to the two anodes as indicated. It will be seen that the alternating potential applied across each of the diodes will be half of the transformer secondary voltage; one anode becoming positive during one half-cycle, the other during the succeeding half-cycle.

Each diode functions as an ordinary rectifier, thermionic current flowing during periods whilst the anode is positive with respect to the cathode, this thermionic current charging the reservoir condenser $C1$ as shown. The condenser thus receives a charge twice during each cycle.

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The output current may be considered as a direct current upon which is superimposed an alternating current component. As the reservoir condenser receives two charges during each cycle, the output alternating current component will have a frequency double that of the input supply.

Operation of the full-wave rectifier is graphically illustrated below (Fig. 91).
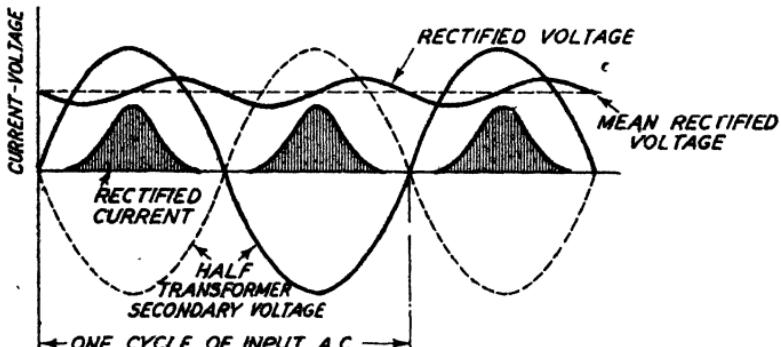
FIG. 91.

The A.C. component of the D.C. output is termed the A.C. ripple and its value assessed as a percentage of the mean rectified voltage.

An approximation, when the rectifier load is small, may be obtained as follows.

Let the mean rectified voltage be V; as the load is light this may be assumed to be equal to the peak secondary voltage V.

The maximum variation in the potential across the reservoir condenser, dV, is due to the load current I flowing for time dt.

If the frequency of the supply is f c.p.s. then dt may be approximated to $\dfrac{1}{f}$

The load current I may be roughly assessed as follows:

$$I = \frac{V}{R}$$

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where R is the effective load.

Simple condenser theory states:

Quantity of electricity = current × time = capacity × voltage change.

i.e. $dQ = Idt = C.dV.$

or $\dfrac{V}{R} = I = C.\dfrac{dV}{dt} = C.dV.f.$

$\therefore \dfrac{V}{R.fC.} = dv.$

Thus the percentage ripple $= \dfrac{dv}{V} = \dfrac{1}{R.f.C.}$

What do you understand by half-wave and full-wave rectification? Explain the operation of a thermionic valve half-wave rectifier, illustrating your answer with a circuit diagram.

Rectification is the term applied to any method of obtaining a unidirectional current from an alternating current supply.

A half-wave rectifier is one which suppresses alternate half-cycles of the alternating current input, the output being a pulsating unidirectional current.

A full-wave rectifier utilises the whole of the alternating current wave, alternate half-cycles being reversed by the rectifier. Again the output is a pulsating direct current, the pulsations occurring at double the frequency of those produced by a half-wave rectifier operating from the same supply.


FIG. 92.

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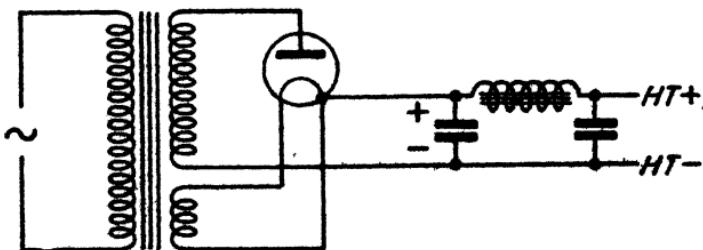
Fig. 92 (*a*) shows a single diode used as a half-wave rectifier. The mains transformer supplies alternating current at a low voltage, usually 4*V*, to heat the filament, and also at a sufficiently high voltage to provide the requisite H.T. supply.

The alternating potential induced across the H.T. secondary winding is applied between the anode and cathode of the rectifier. When the anode is positive, that is during positive half-cycles, thermionic current will flow through the valve, charging condenser $C1$ as shown. During negative half-cycles no thermionic current will flow through the diode, thus the charge on $C1$ will be unaffected, assuming there is no leakage. If an external load is applied across the output of the rectifier (marked H.T. + and H.T. —) $C1$ will begin to discharge, but if the load is not greater than the output of the rectifier, the potential across $C1$ will remain sensibly constant.

Condenser $C1$ is frequently termed the reservoir condenser for obvious reasons, although in later years the components $C1$, $C2$ and $L1$ have been considered as a smoothing unit or L.F. filter, inserted to flatten out the alternating current ripple at the supply frequency, superimposed on the direct current output.

Below is a series of curves illustrating the operation of a half-wave rectifier, Fig. 93.
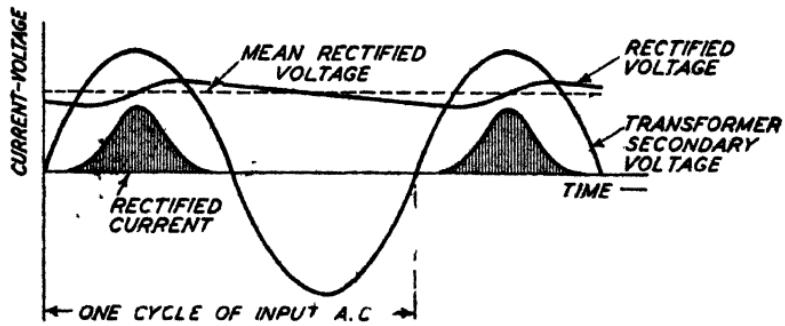
FIG. 93.

What is a Mercury Vapour Rectifier?
What precautions are necessary in its use?

A Mercury Vapour Rectifier is a "soft" diode, the gas remaining in the valve being mercury vapour.

In addition to the vapour, a quantity of metallic mercury is also present.

The Mercury Vapour Rectifier may be used in any standard half-wave, full-wave, or voltage doubling circuit.

There are two operating conditions against which special precautions must be taken:

(1) As the cathode requires up to 20 seconds in which to reach the point of maximum emission, application of high tension voltage to the anode must be deferred until at least 30 seconds after the heater is switched on. Failure to observe this precaution will result in there not being sufficient cathode emission to ionise the mercury vapour and prevent the potential difference across the tube rising above 22 volts, the value above which disintegration of the cathode is probable.

(2) As an accidental short circuit of the rectifier load would cause the full alternating mains voltage to be applied across the tube, with disastrous effects on the cathode, special care must be taken to prevent this occurring.
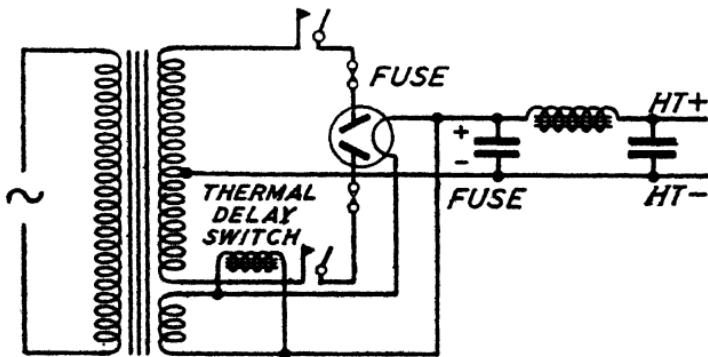

FIG. 94.

Prevention of (1) is achieved by inserting a thermal delay switch in the A.C. supply to the anode of the rectifier and (2) by the use of a suitable fuse or overload cut-out in the anode circuit of the valve.

Connection of the preventive devices in a full-wave rectifier circuit is illustrated in Fig. 94.

Describe the operation of a Mercury Vapour Rectifier.

Fig. 95 illustrates a Mercury Vapour Tube used as a half-wave rectifier.
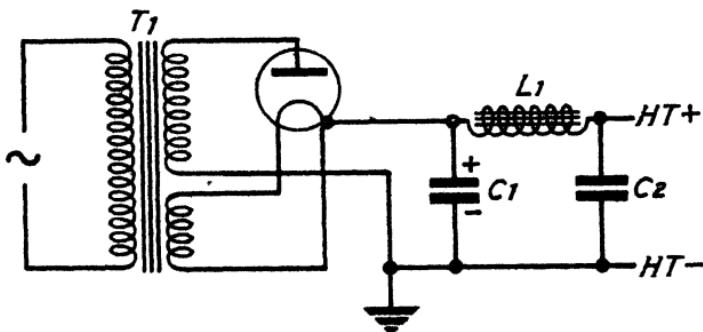
FIG. 95.

When the cathode of the rectifier is heated, electrons are emitted, some being attracted to the anode during half-cycles when the anode is at a positive potential with respect to the cathode, the remainder forming a negative space charge around the cathode. Whilst traversing the intervening space, frequent collisions occur between the electrons and the mercury molecules. If the velocity of the electrons at impact is sufficiently great, the mercury molecules may be split up into ions.

It is found that the potential difference between the anode and cathode necessary to ionise the mercury vapour is approximately 15 volts. At this potential the emitted electrons are just capable of completely ionising the mercury vapour.

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A potential difference of less than 15 volts across the diode produces only a small electronic current, the internal resistance of the tube being comparatively high, but attainment of the ionising potential is accompanied by a sudden tremendous increase in current, the internal resistance decreasing almost to zero. Existence of this condition is indicated by the appearance of a blue glow which permeates the whole valve.

As the operating internal resistance of the mercury vapour tube is very low, its voltage regulation is good, in fact this type of rectifier is a very near approach to the perfect rectifier.

A simple explanation of the vast increase in anode current when ionisation of the mercury vapour occurs, is that the positive ions produced neutralise the negative space charge existing around the cathode, all electrons then emitted by the cathode being attracted to the anode as fast as they are emitted.

This condition will exist only as long as the potential difference across the tube does not fall below 15 volts.

It has been found that if the positive ions present during ionisation fall through a potential greater than approximately 22 volts before striking the cathode, the surface of the cathode is liable to disintegrate.

As long as the potential across the tube remains between 15 and 20 volts there is little likelihood of damage to the cathode.

RECEIVING AND TRANSMITTING AERIALS

(*a*) *State the main advantages of electromagnetic waves over light waves for communication.*
(*b*) *Is the velocity of electromagnetic waves and light waves the same.   What is the velocity of light?*
(*c*) *Signals are received on a wavelength of 32·5 metres.   What is the frequency of transmission?*

(*a*) The advantages which electromagnetic waves have over light waves for communication are as follows:

(i) They follow the earth's curvature and therefore the range of communication can be increased beyond the limits of the horizon. With light waves it is necessary that the point from which a ray of light is being received should be above the horizon.

(ii) Electromagnetic waves will pass through or over intervening objects, such as buildings, etc. Light waves cannot pass such obstructions and communication would be broken by these intermediate objects.

(*b*) The velocity of electromagnetic waves and light waves is the same.   This velocity is 300,000,000 metres per second or 186,000 miles per second.

(*b*)
$$\text{Frequency} = \frac{\text{Velocity}}{\text{Wavelength}}$$
$$= \frac{300,000,000}{32\cdot5}$$
$$= 9,230\cdot7 \text{ Kilocycles.}$$

Frequency of transmission is 9,230·7 Kilocycles per sec.

*(a) **What is a radiating circuit?***
How is the radiation resistance and radiation
efficiency of an aerial obtained?
*(b) **What is the radiation resistance of an aerial***
transmitting 1 Kilowatt if the current supplied is
100 amperes?

Any circuit such as an aerial, which is capable of radiating electromagnetic waves when alternating currents of suitable frequency flow, is known as a radiating circuit.

The radiation resistance of an aerial is obtained by dividing the power in watts radiated, by the square of the current in amperes. Stated mathematically:

$$\text{Radiation resistance } R = \frac{P}{I^2} \text{ ohms.}$$

The radiation efficiency is the ratio of the energy transmitted to the energy supplied to the circuit, and is usually expressed as a percentage.

(b) The radiation resistance of the aerial is

$$R = \frac{P}{I^2} = \frac{1000}{100 \times 100}$$
$$= 0\cdot1 \text{ ohm.}$$

What is an Aerial? How is the wavelength of an
aerial increased or decreased? Are there any
detrimental effects that accompany the increase
of the wavelength?

An aerial is a conductor (or a number of conductors) used for the purpose of transmitting or receiving electromagnetic waves. It can take the form of an elevated wire or wires insulated from earth, or in the form of an insulated conductor wound on a framework in case of ordinary reception.

The wavelength of an aerial can be varied by adding inductance or capacitance in series with the aerial as shown in Fig. 96. The wavelength is increased if inductance is added to the aerial in series, and decreased if capacitance is added.

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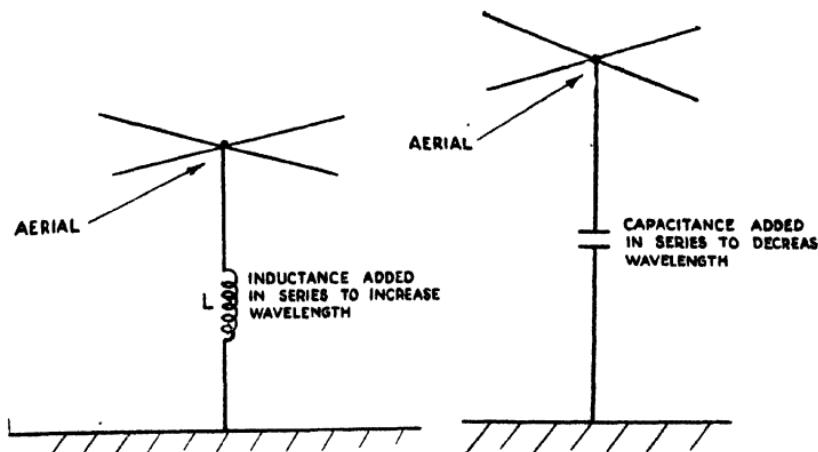
FIG. 96.

·By placing a "lumped" inductance in series with the aerial to increase its wavelength the open oscillatory circuit of the aerial tends to become a closed oscillatory circuit with the result that the radiating strength of the aerial is reduced. There is, therefore, a limit to the amount of inductance that can be inserted into the aerial without affecting its efficiency as a radiator. Generally speaking, the wavelength of an aerial can be doubled without seriously affecting the radiation.

What do you understand by the natural inductance and natural capacitance of an aerial system?

Natural inductance of an aerial system.

The natural inductance of an aerial system is the combined inductance of all the conductors forming the aerial together with the inductance of the leads to and from the aerial. See Figs. 97 (*a*) and (*b*).

Natural capacitance of an aerial system.

The aerial wire acts as one plate of a condenser and the earth as the other; this also includes the leads to and from the aerial. This capacitance of the leads and aerial is known as the natural capacitance of the aerial.

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The portions of the aerial system nearer the ground have greater capacitance than those portions of the aerial and leads further above ground because of the greater space between the aerial conductor and earth.

(a)

(b)
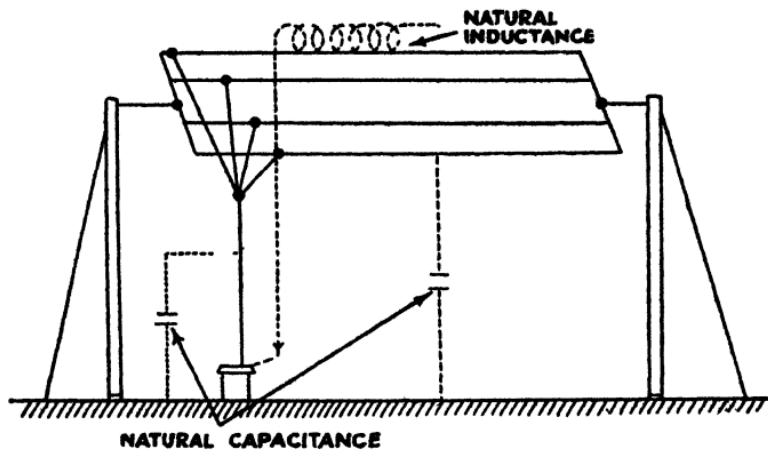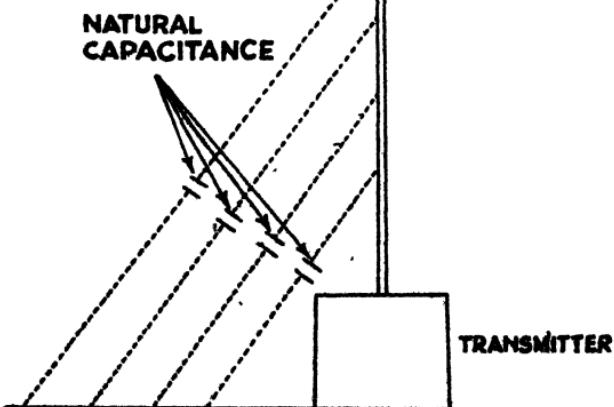
FIG. 97.

Fig. 97 (a) shows the natural inductance and natural capacity of a roof-type aerial, while Fig. 97 shows very clearly the distribution of the natural capacity of vertical aerial.

Write a short account of aerial radiation and explain with the aid of a diagram the meaning of the terms true and virtual height of a reflected wave. Draw a graph showing how the angle at which the wave is radiated and the height of the ionized layer determine the distance from the transmitter of the reflected wave.

When an aerial is energised, radio frequency rays are radiated out into space.   Fig. 98 shows the rays leaving an aerial at all angles of elevation from 0°— horizontally to 90°— vertically.   Under practical conditions it is rarely possible for a ground aerial to radiate
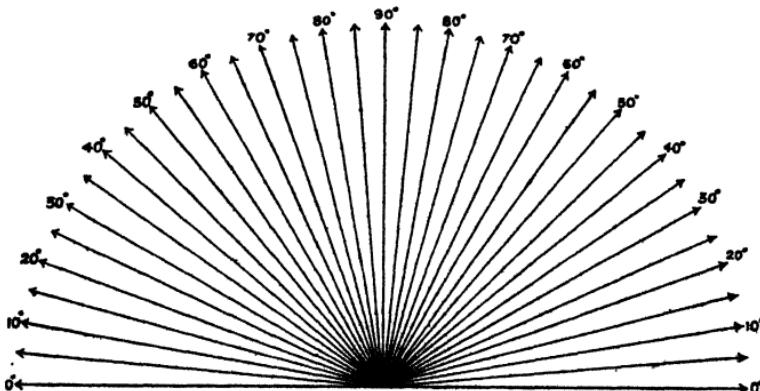
FIG. 98.

any energy below approximately 4°, and in some cases little energy is radiated below 20°.   The illustration therefore shows an ideal rather than an actual case. Again, the amount of energy radiated at a given angle depends on the height of the aerial, its natural frequency and its design.   It is, however, convenient to assume that the rays provide communication over the surface

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of the earth by means of the low angle rays and through the medium of the sky, by utilising the remaining rays.

The rays with angles of radiation between approximately 0° and 5° by a process of diffraction follow the earth's curvature and provide ranges which vary with the type of terrain over which the rays are travelling.
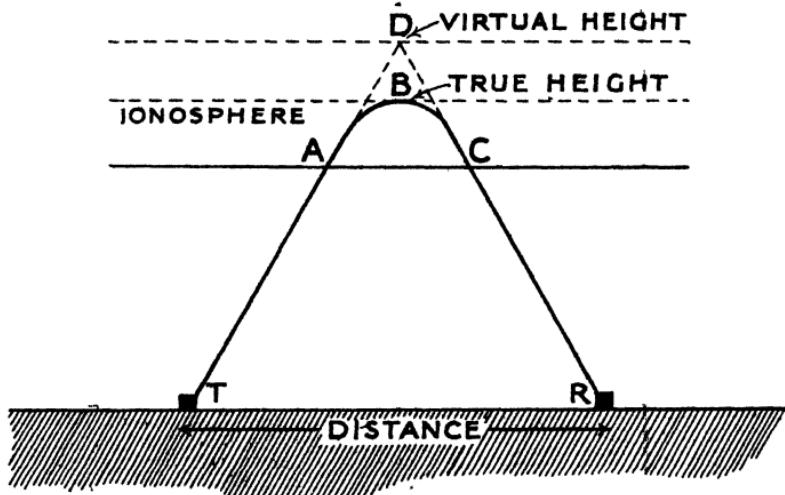
FIG. 99.

Over sandy soil even with high-power transmitters the ranges are very small and are greatest when directed over the sea. This variation in range is due to energy being absorbed from the rays as they radiate outwards. The absorption is greatest on the very high frequencies and becomes less as the frequency is lowered, until on frequencies between 50 and 100 Kc/s. it is very small. Because of this fact, when medium distance transmissions are required over land, use is usually made of low or medium frequencies. Over sea, however, owing to the low level of absorption H/F surface rays have useful ranges.

The rays from the aerial radiated at angles between approximately 5° and 90° are projected towards the sky and eventually reach an electrified region many miles above the earth's surface. On entering this

region, the rays are gradually bent round and return to earth again. This action is shown in Fig. 99 where for simplicity in illustration one ray only is shown. Although it is correct to say that the ray is bent for the purposes of calculation, it is assumed that the process of gradual bending is replaced by simple reflection at a surface considerably higher than that to which the ray actually penetrated. In Fig. 99 $T A B C R$ is the actual path of the ray; $T A D C R$ is the assumed path. The height of this equivalent reflecting surface is known as the virtual height and is one of the important factors in frequency calculation. If the angle at which the ray leaves the aerial is known, allowing for the curvature of the earth, it is possible to determine the distance at which the ray will return to earth after reflection from a given height. The approximate distance is shown on the graph Fig. 100.

(a) *Define the term " fading " and state the cause of this phenomenon.*

(b) *What is " selective fading "?*

(c) *What are the causes of fading in the case of*
  (1) *Medium-wave stations within range of the ground ray?*
  (2) *Short-wave stations beyond range of the ground ray.*

(a) "Fading" is the variation in strength of signals received from a distant transmitter. It may be caused by changes in the reflecting properties of the ionised layers of the atmosphere, or by the *indirect ray* reflected from these layers sometimes opposing the *direct ray* received.

(b) High-frequency electromagnetic waves differing slightly in frequency very often fade independently of each other. Thus in the case of a Radio Telephone Transmitter with a frequency spread of 9 kilocycles it is possible for the different frequency components of the modulated wave to fade quite independently of each

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RADIATION ANGLE
VERSUS
DISTANCE AT WHICH SKY RAY RETURNS TO EARTH
(SINGLE REFLECTION)
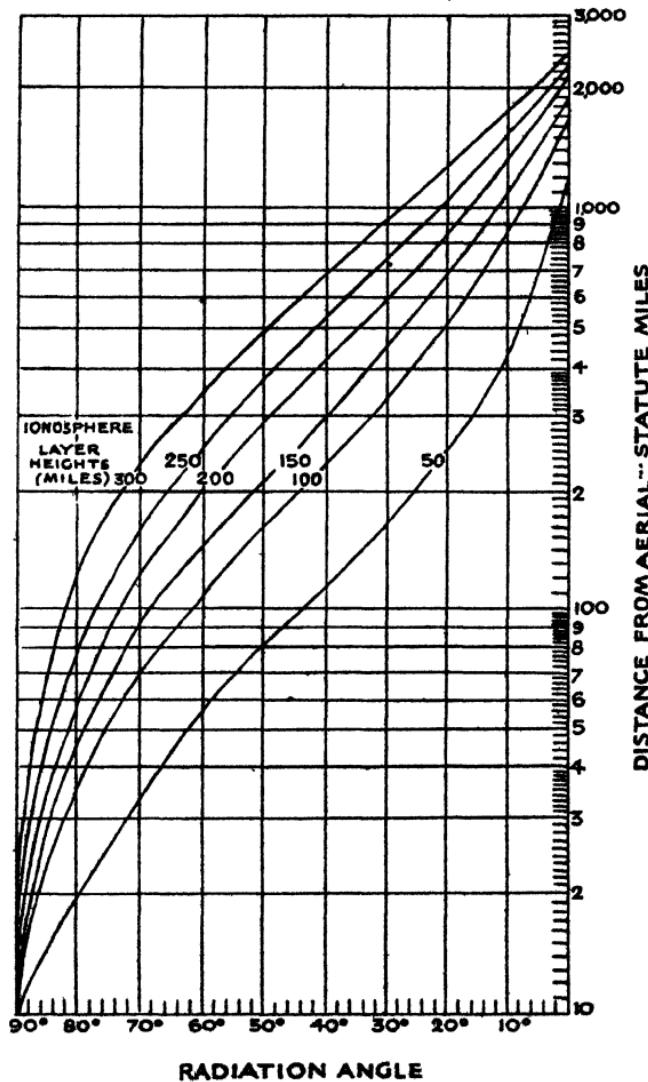
FIG. 100.

other, thus causing frequency distortion. This type of fading is known as selective fading.

(c) Fading of medium-wave stations within range of the ground wave occurs mainly at night owing to the decreased attenuation of the sky wave after sunset. It is due to interaction between the ground waves and waves reflected from the ionised (Heaviside) layer.

The radiation from a short-wave station may occur at all angles to the horizontal. Reception at distant points outside the range of the ground wave is due to reflection from the Appleton or F layers. Rays projected at different angles to the horizontal will reach the receiver by paths of different length. The components of the various waves will differ in phase. The resultant signal will therefore fade or vary. Variations in the height and density of the layer introduce fading. In this case therefore, fading is caused by interaction between different indirect rays due to variations in reflection from the Appleton layers.

Explain with the aid of a diagram, the meaning of the terms skip distance and skip zone. How do these vary with the power transmitted, the time of the day and season? Is it possible to receive signals from the station whilst in the skip zone?

Skip distance and skip zone can be best explained by reference to figures 98 to 101, which illustrates the fields associated with a short-wave transmitter transmitting in all directions.

The skip zone is the area surrounding the station between the points where the field strength of the direct rays becomes negligible and the points where the first indirect rays or sky waves are returned to the earth. The skip distance is the distance across the zone in any direction from the transmitter. The position of the inside edge of the zone varies with the power radiated, the nature of the terrain and the frequency of transmission. It does not vary with the

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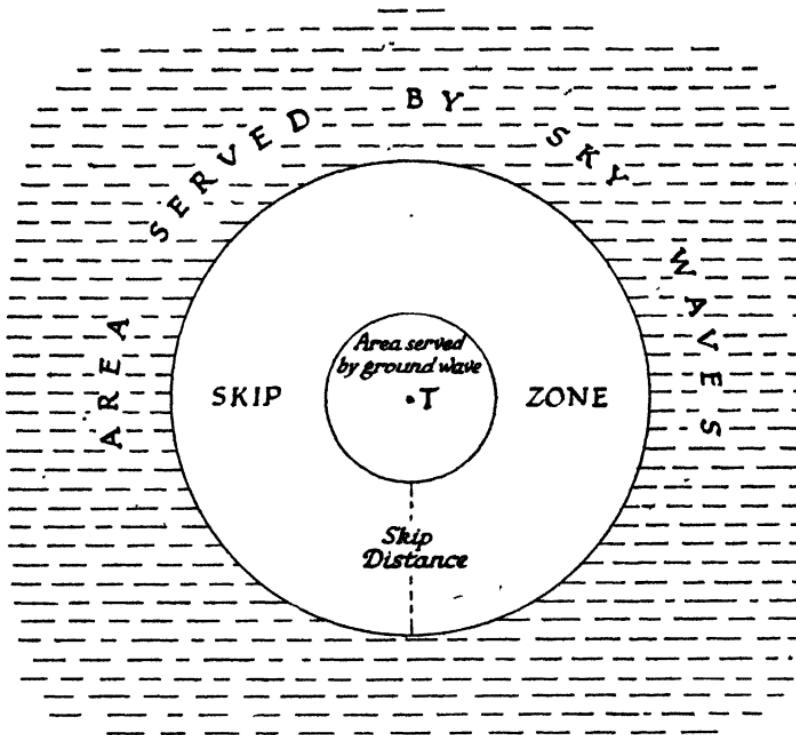
ILLUSTRATING SKIP DISTANCE *and* SKIP ZONE

(*Aerial Transmitting in All Directions*)

FIG. 101.

time of day. The position of the outside edge is determined by the position of the ionisation layer and therefore varies considerably with the frequency used, the time of day and the season of the year. It is independent of the power radiated from the station.

It is possible to receive signals whilst in the skip zone, though reception would be very poor; such signals are the result of a scattering effect under certain conditions from the ionised layer.

***Explain with the aid of diagrams the two methods
of aerial excitation.***

The two methods of aerial excitation are known as:

(*a*) The direct aerial excitation system.

(*b*) The mutual inductive aerial excitation system.

Figures 102 (*a*) and (*b*) show the respective arrangements.

In the direct aerial excitation system the aerial itself may act as the tuned circuit, the condenser then

(*a*)   (*b*)
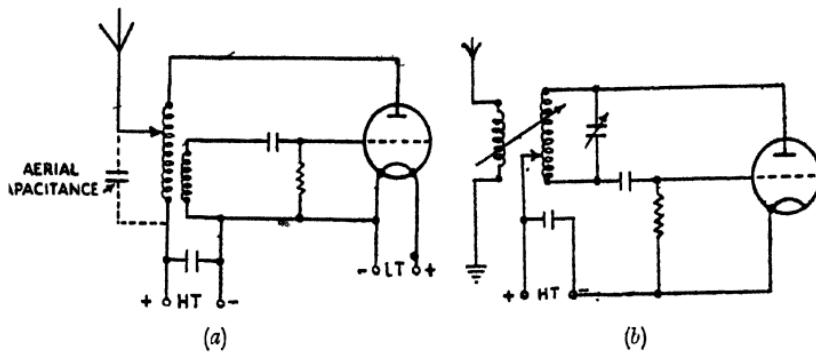
FIG. 102.

corresponds to the distributed aerial capacitance to earth and the inductance to the natural inductance and the artificial inductance in series.

With mutual aerial excitation the aerial is a separate open oscillatory circuit coupled to the valve tuned circuit which is then a closed oscillator. The coupling is usually mutual inductive.

***What are the advantages of mutual inductive
aerial excitation compared with direct aerial
excitation?***

Mutual inductive aerial excitation has the following advantages:

(*a*) Valves are constructed to be capable of dissipating a certain amount of power at the anode with safety. The insulation of the aerial (if an open oscillatory circuit is employed) may sometimes fall

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to a very low value due to heavy rain, snow or some other reason, the load thus thrown on the valve may be so great that the circuit stops oscillating. Under these non-oscillatory conditions the whole of the power taken from the H.T. supply is dissipated at the anode of the valve instead of the usual percentage (30–50%) and the valve may be burnt out. If, however, a mutually coupled circuit is used, the closed circuit continues to oscillate and to absorb its share of the power. The closed circuit is always trying to produce forced oscillation in the aerial and hence it tends to dry off the moisture from the aerial insulators.

(b) Harmonics in a self-oscillatory circuit with negative grid bias always occur. With direct aerial excitation, energy at the frequency of these harmonics is radiated without any limitations and produces undesirable interference.

When mutual excitation is employed, the aerial circuit is naturally tuned to the first harmonic, and so presents considerably less impedance to the E.M.F. induced in it at this frequency than it does to the E.M.F's induced by the higher harmonic currents flowing in the closed oscillatory circuit. Thus the higher harmonic currents in the aerial circuit are considerably reduced in amplitude compared with the first harmonic current, and correspondingly less energy is radiated at these unwanted frequencies.

In addition, the proportion of harmonic to fundamental current flowing in the inductive branch of the primary circuit is considerably less than the corresponding proportion in the make-up (anode) current, for the capacitative branch of the primary tuned circuit presents less reactance to these higher frequency currents than does the inductive branch.

(c) Variation of the natural frequency of self-excited oscillations occur. One common cause of such variation arises through changes in aerial capacitance. These changes may be due to the aerial swaying with the wind.

With direct aerial excitation these changes in capacitance are directly operative in altering the L.C. value of the oscillatory circuit, and therefore the transmitted frequency. They also alter the L/C ratio of the tuned circuit, and so affect the oscillatory power transferred from the valve.

With a closed oscillatory circuit and coupled aerial variations in aerial capacitance still operate directly in the same way, but this effect then depends also on the coupling factor.

With loose coupling the variations in frequency due to this cause may therefore be greatly reduced. Mutual aerial excitation is particularly advantageous at high frequencies where an untuned coupled aerial is usually employed. In this case, variations in aerial capacitance have a completely negligible effect. With direct aerial excitation variations in aerial capacity would then produce the greatest actual changes in the transmitted frequency, the percentage variation remaining the same.

The obvious disadvantages of mutual aerial excitation is that two circuits are maintained in oscillation with a corresponding increase in damping losses. Also, the looser the coupling, the smaller is the amount of energy transferred to the aerial circuit. Of more importance, however, is the avoidance of a phenomenon known as "frequency jump" which occurs in valve transmitters with tightly-coupled aerial circuits. It never occurs in loosely-coupled circuits.

Define the term " Polar Diagram."
Give the polar diagram of an aerial system of four verticals with half wave-length spacing. What would be the effect of increasing the number of verticals to eight with the same spacing.

A "Polar diagram" is a curve showing the values of the field strength produced at a constant distance in various directions around a wireless transmitter. The polar diagram of a single vertical is a circle. If

two such verticals correctly fed and spaced half a wave-length apart are energised, the polar diagram becomes a figure eight.

A further increase of the number of verticals results in the figure eight becoming narrower. Fig. 103 (a) gives a polar diagram of an aerial having four verticals with half wave-length spacing, while Fig. 103 (b) is of that an eight-element system.

(a)   (b)
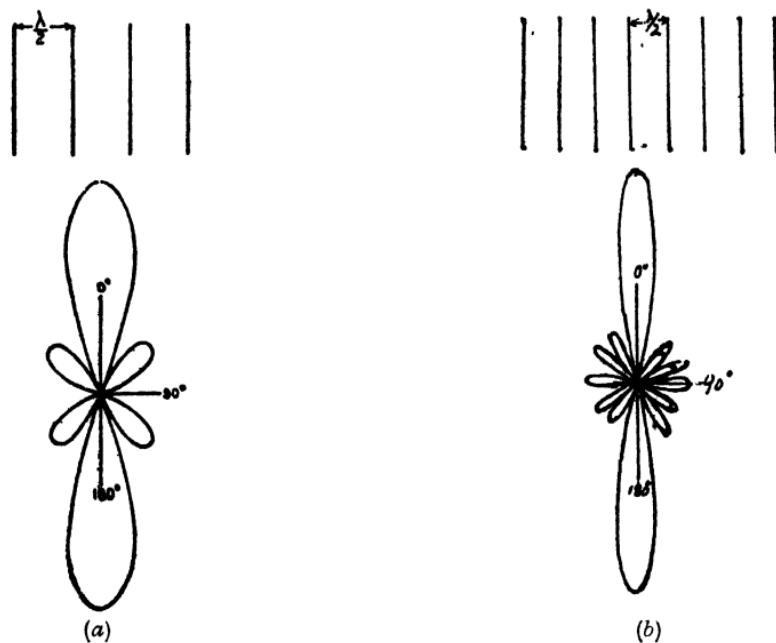
FIG. 103.

Explain with the aid of a diagram the effect of reflectors on a vertical aerial array.

Considering a single vertical aerial with another wire (isolated) placed a quarter of a wave-length $\left(\dfrac{\lambda}{4}\right)$ away. When current flows in the aerial, a magnetic field is set up around the wire which travels outwards in all directions with the speed of light. This field

thus arrives at the other (reflector) wire after it leaves the aerial by a time interval corresponding to a lag of 90°. If the current is an alternating one, the magnetic field also varies and is cut by the conductor forming the reflector. By Lenz's Law, this causes a current to flow which tends to reduce the magnetic flux producing it, i.e. a current lagging by 180° (opposite in phase). Since the magnetic field has already a lag of 90° owing to its time of travel from aerial to reflector, the current flowing in the reflector lags 270° in phase behind that flowing in the aerial. The magnetic field from this, therefore, is travelling forward in the direction of the aerial and arrives in phase with the originating magnetic field, while the field travelling in the direction aerial to reflector is cancelled out. Thus the wave travelling in the forward direction is increased and that travelling backward diminished in intensity. Intermediate angles will give intermediate results owing to difference in phase and the resulting diagram will be a cardoid or heart-shaped diagram as shown in Fig. 104.

Fig. 105 shows the polar diagram of 4 verticals $\frac{\lambda}{2}$ spacing fitted with reflectors.
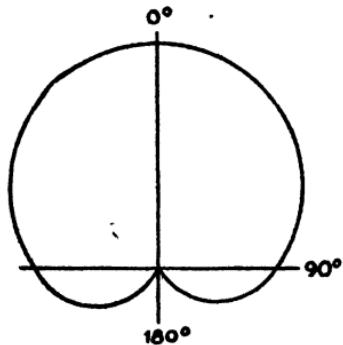
Single vertical aerial $\frac{\lambda}{2}$ spacing with reflector $\frac{\lambda}{2}$ away

Fig. 104.
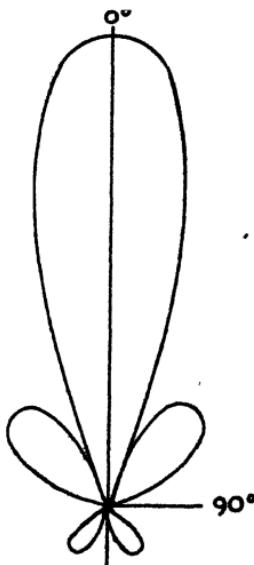
Four verticals aerial with reflectors

Fig. 105.

Thus the combination of these two arrangements, viz, a series of aerials spaced half a wave-length apart, with a further series of reflectors behind at a distance of a quarter of a wave-length, constitutes a very effective directive or "Beam" system. If a number of such aerials can be disposed one above the other and so fed that the currents are all in phase, a further increase in the radiation will be obtained.

Describe briefly a long wire directional aerial suitable for both transmission and reception at frequencies around 50 Mc/s.

An aerial especially suited to the transmission and reception of 50 megacycle horizontally, polarised signals, is the Horizontal Diamond or Rhombic Aerial. The arrangement is shown in Fig. 106.
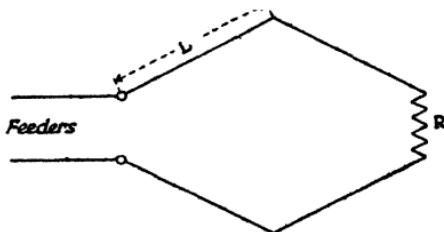
FIG. 106.

The aerial is commonly made up of two horizontal V's placed end to end but the method of construction may be varied to provide the requisite radiation angle and directivity.

The value of resistance R is chosen to ensure that it will absorb all energy which would be transmitted to or received from the rear of the aerial, a common value being from 600 to 800 ohms.

For transmission, the resistance must absorb some 50 per cent of the total transmitter output, thus it is essential that the type of resistance chosen should be capable of dissipating the necessary power.

When used as a receiving aerial, correct adjustment of R can result in almost complete rejection of interference from the rear.

In practice the length of each of the four sides is made equal to at least twice the operating wave-length.

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The Rhombic aerial is admirably suited for use on Ultra Short Wave point-to-point links, utilising one aerial for both transmission and reception.

Find the voltage induced by a plane wave of field strength 0·01 volt per metre and wave-length 300 metres in a vertical aerial 8 metres high.

The voltage induced in an aerial can be obtained by use of the formula.

$$E = Fh \text{ volts.}$$

where F is the field strength in volts per metre.
and h is the effective height of the aerial.
Substituting the values given.

$$E = 0·01 \times 8 \times 1000 \text{ Millivolts.}$$
$$= 80 \text{ Millivolts.}$$

The current measured at the base of a radio-telegraph antenna is 220 amperes. The antenna is of L form with a " radiation height " of 160 feet and the wave-length employed is 8000 metres. Find the power radiated.

The power radiated is given by the formula

$$\rho = \frac{160 \, \pi^2 \, I^2 \, h^2}{\lambda^2} = \frac{1580 \, I^2 \, h^2}{\lambda^2} \text{ watts.}$$

where I is the current in amperes.
h is the effective height $\rbrace$ same
λ is the wave-length $\rbrace$ units.
Substituting values given

Power in kilowatts equals
$$\frac{1·580 \times 220 \times 220 \times 48 \times 48}{8000 \times 8000}$$
$$= 2·75 \text{ kilowatts.}$$

(Note 160 ft. = 48 metres.)
Ans. Power radiated = 2·75 kilowatts.

Find the voltage induced by a plane wave of field strength 0·01 volt per metre and wave-length 300 metres in a frame aerial 1 metre square of 12 turns,

the plane of the frame being in the plane of propagation of the wave.

The voltage received in a frame aerial in the plane of propagation of the wave is given by the formula:

$$E = \frac{2\pi \, F \, A \, N}{\lambda} \text{ volts.}$$

where F is the field strength in volts per metre.
λ is the wave-length in metres.
A is the frame area in square metres.
N is the number of turns.

Substituting the values given.

$$E = \frac{2\pi \times 0\cdot01 \times 1 \times 12 \times 1000}{300} \text{ millivolts.}$$

$$= \frac{2\cdot4\,\pi}{3} = 2\cdot51 \text{ millivolts.}$$

Ans. The voltage induced in the aerial is $2\cdot51$ millivolts.

What is the radiation resistance of an aerial having an effective height one hundredth of the length of the wave emitted?

The power radiated $\rho = I^2 R$
where I is the current in amperes.
and R is the radiation resistance.

but radiation resistance $R = 160\,\pi^2 \dfrac{h^2}{\lambda^2}$

where h is the effective height of the aerial.
and λ is the wavelength.

$$\therefore \; I^2 R = I^2 \times 160\,\pi^2 \frac{h^2}{\lambda^2}$$

dividing throughout by I^2

$$R = 160\,\pi^2 \times \frac{h^2}{\lambda^2}$$

$$= 160 \times 9\cdot8696 \times \frac{1}{10,000}$$

$$= \frac{1578}{10,000} = 0\cdot1578 \text{ ohms.}$$

Ans. The radiation resistance is $0\cdot1578$ ohms.

CHAPTER VIII

SHIP–SHORE RADIO

Write a short account of the " service " given to ships at sea by Coast Stations.

Service to ships provided by British stations falls broadly into four categories.

1. *Coastal Service.* For this service the coast stations operate on frequencies between 375 and 500 kc/s, and in addition maintain a short-distance radio telephone service on 1650 kc/s.

The normal range of a coast station is up to 300 miles by day, but this distance is greatly exceeded during the hours of darkness. The service given to ships in the 375–500 kc/s band is almost entirely telegraphic.

The radio telephone on 1650 kc/s is primarily intended for communications to and from Coasters and small craft who do not normally carry a radio operator. Some coastal stations are in a position to connect a ship fitted with R/T to telephone subscribers ashore. Direct two-way communication is possible under favourable conditions.

2. Service by certain stations fitted to work to ships fitted with high-frequency apparatus.

These stations operate on frequencies of the order of 6000–16,000 kc/s.

These stations have almost world-wide range.

3. A broadcast service to ships also operates. For this service a transmitter of very high power on a frequency of the order of 15 kc/s is used.

The range of this transmitter is world-wide.

4. Some of the largest luxury liners operate a world-wide telephone service. Ships fitted with suitable apparatus can give two-way telephone service to almost any telephone subscriber in the world.

What is the function of the automatic alarm receiver installed in some ships?

A regular watch for distress calls is kept on all ships compulsorily equipped with wireless, so that when a ship finds herself in distress but beyond the range of coast stations, assistance may be afforded by other ships within range.

The auto-alarm receiver is designed to respond to the auto-alarm signal.

This signal consists of twelve four-second dashes spaced by one second intervals.

On the operation of the auto-alarm signal, bell alarms operate in the radio room, radio operators' cabin, and on the ship's bridge. The alarm indicates that a ship in the vicinity is transmitting the auto-alarm signal which will be followed after an interval of two minutes by the distress message. The distress message consists of the distress call S O S, S O S, S O S followed by the distress particulars.

The alarm signal is sent two minutes before the distress signal (S O S), to enable operators to reach their sets and be ready to receive the distress signal and particulars.

Explain with the aid of a simple block schematic diagram the action of the automatic alarm equipment. How does this equipment discriminate between ordinary signals and distress signals on 500 Kc/s.

The automatic alarm equipment is associated with a special receiver and consists of an anode bend detector and a number of relays. Fig. 107 is a block schematic diagram of the apparatus.

Auto Alarm Signals Received.

Relay S operates on receipt of a signal on 500 Kc/s. and its operation sets in motion the first timing arm. The signal will be of 4 seconds duration and will therefore operate the first storage relay. At the end of the
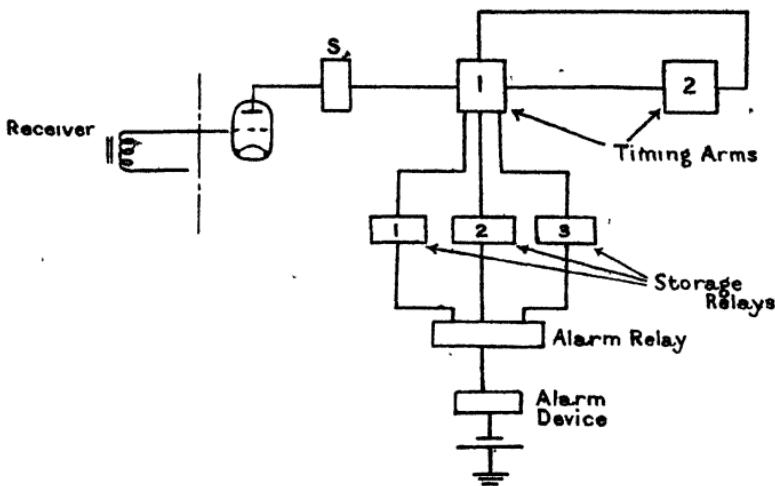
ALARM CALL EQUIPMENT

FIG. 107.

first signal a second timing arm is brought into opera-
tion and on receipt of the second dash signal (received
within 12·4 secs.) a second storage relay is operated
in a similar manner.

A third dash of the required duration operates a
third storage relay which completes a circuit for
operating the alarm relay. The alarm relay contacts
complete a circuit for ringing the alarm device.

The timing arms perform two functions (1) they
time the duration of the signals received and (2) they
check the time interval between receipt of signals.

The automatic alarm apparatus is arranged to
restore to normal at any stage of operation unless the
incoming signals are of the required duration and
spacing. For example, any incoming signal on 500
Kc/s. will operate S relay and the first timing arm,
but if the signal is of shorter duration that 4 seconds
the apparatus will restore to normal on completion
of the signal. If the first signal is of the required
duration then the first timing arm would check on the
time for the receipt of the next signal, and also its

duration.   If a second signal was not received within 12·4 seconds, or if the second signal was not of 4 seconds duration the equipment would restore to normal.   A similar restoration would occur during a third stage of signal reception.

What part does the " radio beacon " play in the navigation of ships?   State one method by which a ship can obtain a bearing whilst at sea?   What frequencies are generally used by radio beacons?

A radio beacon emits an automatic morse signal at regular intervals.   The beacon is allocated an international call sign for purposes of identification, and exact positions of transmitting aerials are published internationally.

Ships fitted with "direction finders" can take bearing of these automatic transmissions.

Two such bearings taken on different beacons will enable the Master of a ship to determine his position with some degree of accuracy.   Before the war an interesting experimental beacon was established on the East Coast.   This beacon transmitted a radio signal and a sound signal simultaneously.   By noting the interval of time between the reception of the two signals it was possible to estimate the distance between the observer and the beacon.

The frequencies allocated to radio beacons are of the order of 300 Kc/s.

Describe two of the chief functions performed by coast stations.   What are the frequencies used by these services?   What procedure is adopted when a ship is in distress?

Two of the chief services performed by coast stations are:

(1) The safety service.
(2) The traffic service.

The frequencies used are between 375–500 kc/s and of the order of 1650 kc/s.

For long-distance and world-wide services of the order of 150 kc/s. If a ship is in distress it transmits by wireless the automatic alarm signal followed by the distinctive morse signal S O S, S O S, S O S on a frequency of 500 kc/s. It is followed by the distress message (name of ship, position, and details of distress).

All stations intercepting a distress call are bound by international agreement to at once acknowledge its receipt, and to render every possible assistance to the ship in difficulties.

How does a ship not equipped with D.F. equipment obtain its bearing by means of a radio? What are the practical distance limits for effective transmission by radio telephony?

To obtain a bearing from a coast station the ship calls the coast station using her international call sign, and requests a bearing (a special 3-letter group is actually used).

When the coast station indicates that it is ready, the ship will transmit her call sign for one minute.

At the end of this transmission the coast station will give the ship its bearing in degrees from the receiving station. The ship will know the geographical position of the coast station and will be able to plot the bearing.

The practical distance limits for effective R/T communication depends upon the frequency and power employed by the transmitting station. Distances up to 300 miles are obtained from the low-power sets normally used on coasters on medium frequencies, and world-wide ranges are obtained from high-power transmitters using high frequencies.

CHAPTER IX

LANDLINE W/T AND R/T INCLUDING R/C TRANSMISSION AND RECEPTION

Describe with the aid of a schematic diagram the principles of operation of a radio telephone channel connected to a land-line.

How is it possible to utilise the same frequency for both transmitters of a radio telephone link?
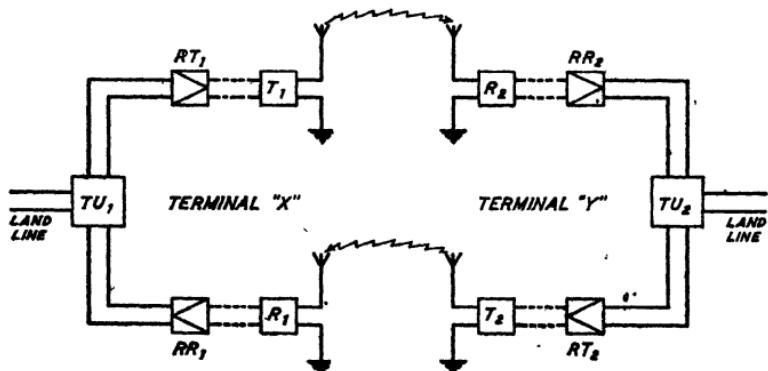
FIG. 108.

Fig. 108 illustrates, in simplified form, the most important items of equipment associated with a radio telephone link.

The land-line from the normal telephone network, usually a trunk switchboard, terminates at the radio terminal on a special unit designed to couple the radio receiver and transmitter with the line, a balance to simulate the land-line impedance being included.

Variable gain audio-frequency repeaters, under the control of the radio terminal operator, are introduced as shown in Fig. 108, to maintain the signals entering the transmitter and land-line at the correct level.

Frequently, the receiver and transmitter forming one terminal of a radio link, are situated at different points, both at a considerable distance from the radio terminal. In a case such as this the receiver and transmitter are linked up with the terminal by means of repeatered telephone circuits. When required, these circuits take the positions shown dotted in Fig. 108.

Operation of the radio link is as follows:

Speech currents from the subscriber connected to terminal "X" enter terminating unit $TU1$. A portion of the audio-frequency current reaches repeater $RT1$, where it is amplified and passed on to the transmitter, the remainder being lost in the output circuit of repeater $RR1$.

Audio-frequency current generated by the receiver, as a result of signals transmitted by terminal "Y," are amplified to their correct level by repeater $RR1$ and passed to terminating unit $TU1$. Here division takes place, half of the current flowing into the land-line, the remainder being lost in the balance. Design of the termination prevents any part of the received signal being passed to repeater $RT1$.

By using different frequencies for transmission from terminals "X" and "Y," simultaneous communication in both directions, often referred to as "duplex" working, may be achieved.

A radio link may be operated on a single radio frequency as long as signals are transmitted in only one direction at a time, and repeaters associated with the opposite transmission path are rendered inoperative.

This is achieved by means of voice-operated relays, or suppressors associated with each repeater. The passage of audio-frequency current through the transmit repeater renders the receive repeater at the same terminal inoperative and vice versa.

What is a hybrid coil?
Describe its mode of operation when associated with the terminal equipment of a radio link.

A hybrid coil is a high-grade multi-winding

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transformer employed to effect conversion of telephone circuits from two-wire to four-wire working, or vice versa, in conjunction with a two-wire line balance.

A radio link may be considered as a four-wire telephone circuit, since separate "go" and "return" paths are used. To permit connection of the four-wire link to the public telephone network, a four-wire–two-wire terminating unit must form part of the terminal equipment.

Operation of the hybrid coil is as follows:

Speech currents incoming from the two-wire land-line circulate via coils EF and JK, inducing similar currents in coils AB and NP. The current induced in coil AB produces a varying audio-frequency potential across the input circuit of the transmit repeater, which amplifies the signal and passes it forward to the wireless transmitter. The voltage produced across the output circuit of the receive repeater by the current induced in coil NP is lost.

Audio-frequency currents produced by the radio receiver are amplified by the receive repeater and flow through coils NP and QR. Since the two-wire balance possesses an impedance approximately equal to that of the two-wire land-line, similar currents are induced in EF, JK and GH, LM, the former flowing via the land-line, the latter being lost in the balance.

What do you understand by the terms " singing " and " clipped speech " when applied to a radio telephone channel?
How may these difficulties be overcome?

Singing is the term applied to the audio-frequency oscillation which occurs in a radio telephone link, due to one of the following causes:

(a) An imperfect balance at the junction of the four-wire link and two-wire land-line.

(b) A gain on the radio link due to variations in transmission conditions.

Clipped speech is the phrase applied to the loss of the
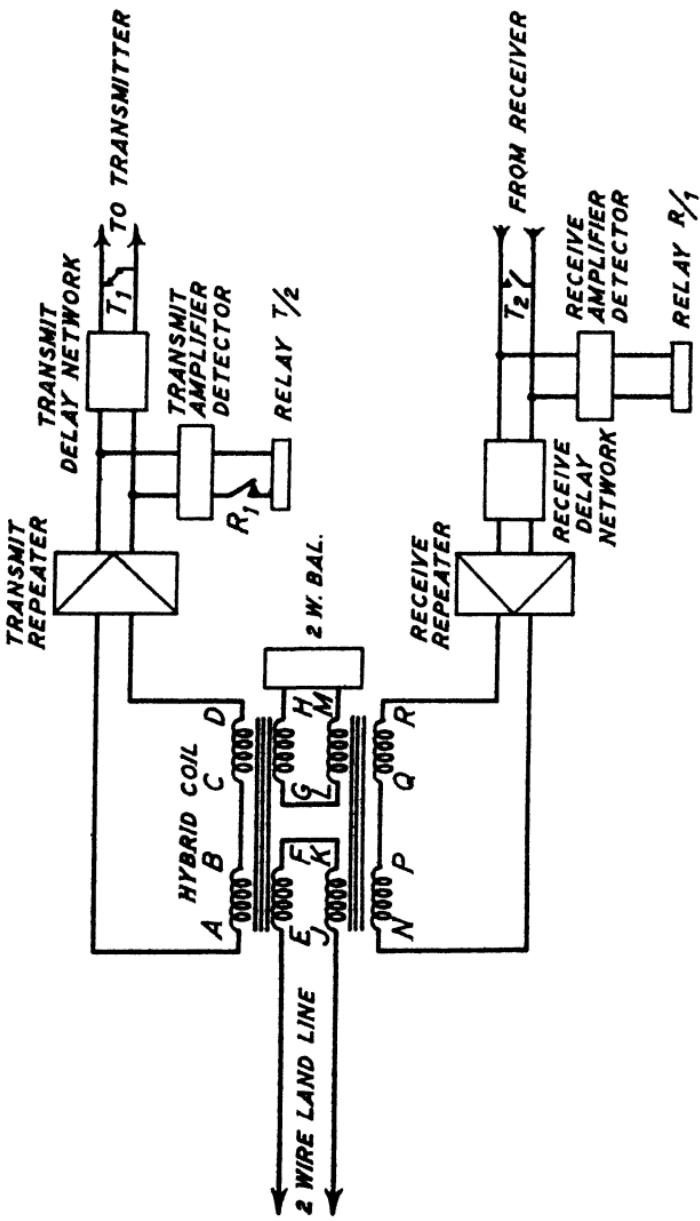
FIG. 109.

first syllable of a signal passing over a radio-telephone link caused by the operate lag of the singing suppressors. If the suppressor requires x milliseconds to operate, the first x milliseconds of the signal will be lost, unless suitable precautions are taken.

Singing and clipped speech are prevented by the introduction of singing suppressors, and delay networks, respectively, as shown in Fig. 109.

In the condition of rest it will be observed that the transmit path at both terminals is short-circuited by contact $T1$ and the receive path is capable of accepting signals.

Considering one terminal only, suppose an audio-frequency current is received from the two-wire line. A portion of the signal is applied to the output circuit of the receive repeater and is lost, the remainder reaches the input circuit of the transmit repeater and after amplification is passed on to the transmit amplifier detector and the transmit delay network. Uni-directional current produced by the detector operates relay T whose contacts operate approximately 25 milliseconds after the application of a signal to the amplifier detector. $T1$ removes the short circuit from the transmit path and $T2$ renders the receive path inoperative.

The transmit delay network introduces a transmission lag approximately equal to the operate time of relay T, thus by the time the first cycles of audio-frequency current emerge from the delay network the transmit path is clear.

The short circuit across the receive path at $T2$ prevents singing which would result if the transmitted signal returned to coils NP, QR of the hybrid via the distant terminal.

On the termination of signals from the two-wire line, relay T releases, $T2$ restores the receive path and $T1$ again short circuits the transmit path.

The terminal equipment is now prepared to receive signals from the distant terminal.

Audio-frequency signals from the receiver are applied

simultaneously to the receive amplifier detector and the receive delay network. Relay R operates and $R1$ disconnects relay T thus preventing its operation by any speech current which might reach it due to imperfect balance of the two-wire line.

The receive delay network which again introduces a time-lag equal to the operate time of relay R, prevents the first few syllables of the received signal from operating relay T before its disconnection at $R1$.

The output from the receive delay network is amplified by the receive repeater, and enters the hybrid coil. Half the available power passes into the two-wire line, the remainder is lost in the two-wire balance.

What is the distinction between Echo Suppressors and Singing Suppressors?

An echo suppressor is a device intended to eliminate undesired effects due to reflected currents in a telephone circuit. These reflected or echo currents, which are returned to both speaker and listener, become of increasing annoyance value as the echo delay time becomes greater. They are of importance therefore in long coil loaded lines where the transmission velocity
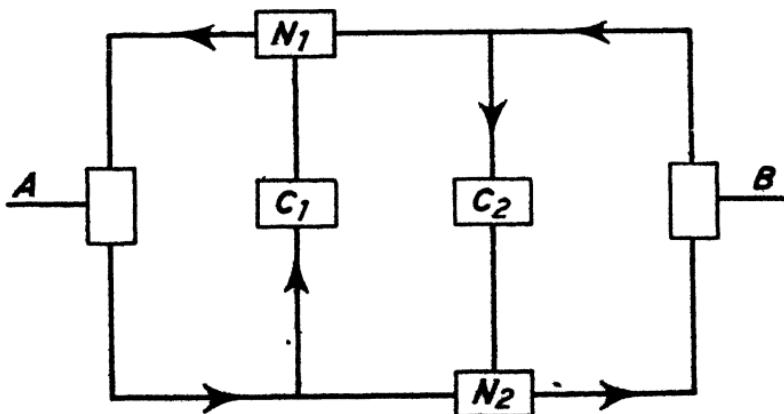

FIG. 110.

is low. Echo suppressors are operated by the speech signals and, when operated, introduce sufficient loss into the return direction of transmission to reduce the echo signal to negligible proportions. They are therefore introduced into the four-wire part of the circuit as shown in Fig. 110.

The control element C_1 is connected to the "go" side of the A circuit and generates a direct current when speech potentials arrive from A. This control current operates on a network N_1, connected in the "return" side of the A circuit, so as to increase its loss considerably.

Similarly, elements C_2, N_2 provide for transmission from B to A.

A singing suppressor is a device intended to suppress the build-up of a voice frequency oscillation in a two-way radio-telephony channel. This oscillation or "sing" is liable to arise as a result of

(a) the imperfect nature of the hybrid balance at the junction of the two- and four-wire circuits,

and (b) the fact that the overall circuit gain may be occasionally positive in a radio link due to transmission variations.

In addition, radio telephone links may need to be operated on the same incoming and outgoing frequency allocations. In order that the near end receiver shall not deliver a signal due to the near end transmitter, it is usual to block the receiving path when the transmitting path is in operation, and vice versa, by a singing suppressor.

Show how the " diode valve " functions in an echo suppressor.

If alternating potentials are applied between filament and anode of the diode, anode current will flow during the time that the anode is positive and stop when the anode is negative. Thus a series of unidirectional pulses can be obtained, the number of

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pulses per second being the same as the frequency of the alternating potential applied. This action is known as "rectification" or "detection" and constitutes the chief function of an echo-suppressor.

Fig. 111 shows the rectifier portion of an echo suppressor circuit.

FIG. 111.
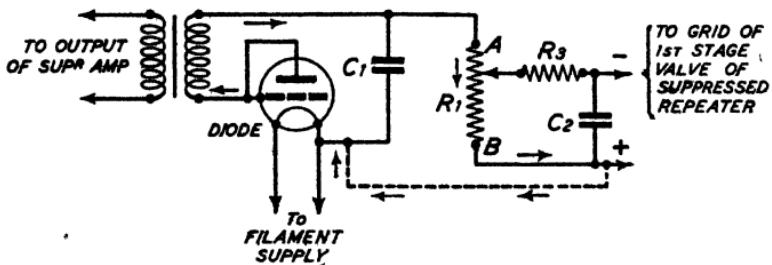
The alternating speech potentials developed across the secondary of the input transformer are applied across the filament and anode of the diode. The condenser C_1 is given pulsating charges due to the rectifiying action of the valve and the potentiometer $R1$ will have a difference of potential across its terminals, the point A being more negative than the point B. This potential is applied as negative bias to the grid of the repeater valve that is to be suppressed.

In what circumstances would the use of ultra-short-wave radio telephone links prove indispensable when setting up an inland telephone trunk network?

What is a six-channel Multi-Modulated Single Carrier System? Enumerate its advantages and disadvantages as compared with a six-carrier Multi-Carrier System.

A trunk network designed to link up the towns and villages of a country depends, in the main, on amplified circuits set up on metallic conductors in underground telephone cables. Occasions arise, however, when for

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various reasons, it proves impossible to link up two places by means of either overhead or underground conductors. Such circumstances are generally occasioned by extremely difficult terrain. For example, the two points to be linked up may be separated by a very rugged valley or by a stretch of water, spanning by aerial or submarine cable being impossible.

When conditions such as these are encountered, it may be economical to set up one or more Ultra Short Wave (U.S.W.) Radio Links to bridge the obstruction, the radio terminals being connected to the telephone exchanges requiring interconnection, by metallic circuits.

U.S.W. radio links are found to be most satisfactory when transmitter and receiver are within optical range, although a comparatively efficient service is possible over greater distances, fading becoming more troublesome as the distance is increased.

Directional transmitting and receiving aerials are normally employed to afford as much privacy as possible and to permit reduction of transmitted power to a minimum.

There are two methods of providing six U.S.W. radio telephone links between two stations:

    (*a*) By utilising individual radio links each with its own aerials, transmitters and receivers, sometimes referred to as a Multi-Carrier System.

    (*b*) By using a six-channel Multi-Modulated Single Carrier System, the carrier wave in each direction of the single U.S.W. link being modulated by the outputs of six modulators.

Advantages of a Multi-Modulated System are as follows:

    (1) Multi-Modulated System requires two aerials on each site, whilst Multi-Carrier System requires twelve aerials on each.

    (2) Multi-Modulated System requires a much narrower frequency band than a similar number of individual links.

(3) Multi-Modulated System requires considerably less equipment.
   (4) Multi-Modulated System requires a smaller power supply.
   (5) Privacy of Multi-modulated Systems is assured, individual channels require special equipment to effect privacy.

Disadvantages of a Multi-Modulated System are as follows:
   (1) Fading of the single U.S.W. link of a Multi-Modulated System affects all channels; all channels of a Multi-Carrier System are unlikely to fade simultaneously.
   (2) Failure of common equipment of a Multi-Modulated System will affect all channels, only failure of power equipment of Multi-Carrier System will stop all channels.

What is an inverter?
Describe its operation, with reference to a block diagram.

An inverter is a privacy device used on radio telephone circuits in which the component frequencies of the speech input are inverted, thus rendering the radio links immune from unauthorised interception.

The most important elements of the inverter are illustrated in the sketch below. (Fig. 112).

INPUT — MOD.1 — OSC.1 — BAND PASS FILTER — MOD.2 — OSC.2 — LOW PASS FILTER — OUTPUT
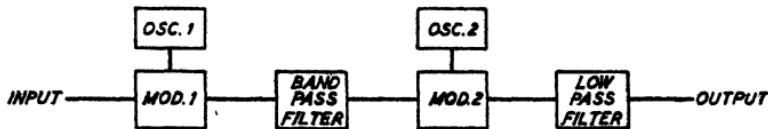
FIG. 112.

The speech input is fed into a balanced modulator (*MOD1*) where it modulates the output from an oscillator (*OSC1*).

The output from *MOD1* is passed through a band-pass filter, which selects one sideband only, into a

second balanced modulator (*MOD2*) where it modulates the output from a second oscillator (*OSC2*).

By arranging the difference in frequency of the two oscillators to be the same as the input speech frequency band, one sideband of the second modulator (*MOD2*) output covers the same frequency band as the original speech input, but with upper and lower frequencies inverted about the mean frequency.

By way of example.

Suppose a speech input frequency band of 0–4000 c.p.s. be accepted by modulator *MOD1*.

Inversion must take place about a mean frequency of 2000 c.p.s.

It follows that a 2000 c.p.s. input tone will be unaffected by the inversion equipment whilst any other frequency f c.p.s. will be displaced and take up a position 4000–f c.p.s.

Suppose the frequency of *OSC1* to be f_1 and that of *OSC2* to be f_2. The output from *MOD1* will consist of sidebands $f_1 - f, f_1 + f$ and any residual oscillator tone of frequency f_1. The lower sideband $f_1 - f$ and f_1 are suppressed by the band-pass filter, the input to *MOD2* being $f_1 + f$ and f_2. The output from *MOD2* will be $f_2 + (f_1 + f), f_2 - (f_1 + f)$ and residual oscillator tone f_2. The low pass filter selects the lower sideband $f_2 - (f_1 + f)$ which may be rearranged as $(f_2 - f_1) - f$.

Now if $f_2 - f_1$ is 4000 c.p.s., an input frequency of f will become 4000 $- f$ in the output, thus inversion of the input speech band has been effected.

Numerically, if f_1 is 10,000 c.p.s. and with a speech input range of 0–4000 c.p.s., the band pass filter must have a pass band of 10,000 $-$ 14,000 c.p.s. If f_2 is 14,000 c.p.s., the low-pass filter must have a pass band of from 0–4000 c.p.s. to pass the lower sideband of the *MOD2* output, the upper sideband 24,000–28,000 c.p.s. and residual oscillator tone of 14,000 c.p.s. being suppressed.

The inverted speech band is used to modulate a transmitter carrier wave in the usual way and demodu-

lation by a normal receiver produces an unintelligible signal.

. If the receiver output is passed through an inverter similar to that used at the transmitter, the original speech output is reproduced.

What disadvantages result from the inclusion of inverters in a radio telephone channel?

The inclusion of inverters in a radio telephone channel tends to reduce its efficiency by the introduction of additional noise and distortion as well as by increasing the fault liability. Voice-operated switching often used to connect the inverter as required in the transmitter and receiver circuits is particularly susceptible to faults. The use of the same equipment for inversion and re-inversion is permissible as both processes are similar.

A further reduction in efficiency results if the inverted speech is carried by land-line between radio terminal and transmitter, or receiver and radio terminal, since attenuation of upper inverted frequencies due to line cut-off causes attenuation of lower speech frequencies on re-inversion.

A further serious disadvantage resulting from the use of the inverter as a form of privacy device, is that interception is possible by using a receiver containing an oscillating detector. By tuning the detector (in a state of oscillation) to the outer edge of one of the transmitter sidebands a readable signal can be obtained in the receiver output.

It is very difficult to prevent the interception of inverted transmissions on the medium and long wave bands but in the case of short wave stations, it is possible to effect a slight periodic change in carrier frequency, insufficient to shift the sidebands outside the acceptance band of the correct receiver, but sufficient to prevent unauthorised reception.

How does the problem of transmitting music and pictures over land-lines differ from that of ordinary

telephone communication? Describe briefly how the special requirements of the former are met.

The transmission of music and pictures over telephone lines necessitates very stringent line conditions as compared with those required for speech transmission Where music is concerned the very considerable increase in the width of the frequency band has an important bearing on the design of the necessary plant. The frequency band of commercial speech extends from about 250 c.p.s. to about 2600 c.p.s., whereas for music transmission of good quality, a range of from 50 to 8000 c.p.s. is necessary. Although efforts are made to reduce distortion where speech is concerned, the effects are not serious provided that the degree of intelligibility is sufficiently high to allow conversation to take place. In the case of music, however, freedom from distortion is of primary importance. The circuits must be free from cross-talk and other unwanted noises. In order to reduce electrostatic interference, the conductors used for music transmission are usually situated in the centre of telephone trunk cables, and are screened with metallised paper. As a high cut-off frequency is required, loading is carefully arranged, and the loading coil spacing is usually half the normal distance, i.e. 1000 yards. Where repeaters are used, care is taken in the design in order to prevent the introduction of distortion, and they must be capable of dealing efficiently with the wider frequency band. The type of coupling used in the amplifiers has an important bearing on the amount of distortion introduced.

Where picture transmission is concerned, the question of constant attenuation is a very important one. Slight variations in the volume of speech or music do not interfere greatly with the reception, whereas in picture transmission any variations in the attenuation will cause differences of density on the picture. For this reason the primary constants of the cable, particularly in the leakance, should be maintained constant. The question of distortion, both in amplitude

and phase is as important as in music transmission, and the conditions as to the type of amplifiers used are the same. Line noises, clicks, etc., although undesirable in speech and music transmission, have more marked effects in the transmission of pictures, as they result in superfluous marks on the picture. For this reason any operations such as monitoring which may introduce clicks, are avoided.

(*a*) **What do you understand by the " characteristic resistance " of a circuit?**
(*b*) *A line 10 miles in length has a total true loop resistance of 175·6 ohms and a total true insulation resistance of 20,000 ohms. What is the characteristic resistance of the circuit?*

(*a*) Every line used for the transmission of current possesses certain properties which are directly detrimental to its efficiency. Where direct current is being transmitted, the two most important factors are the conductor resistance and the leakage resistance which exists between the two lines. If a short line is tested for loop resistance and leakance, the measured loop resistance will be found to be much lower than the resistance between the two lines. If the line is increased in length the conductor resistance increases proportionally, and the resistance between the lines decreases. The latter effect is due to the fact that the various small leakage paths can be considered to be all in parallel. Thus it will be seen that when a very long line is considered, the measured loop resistance is approaching the measured insulation resistance, until with an infinitely long line the two values would be equal. If it were possible to measure such a line ·from the sending end, the same resistance would be obtained whether the distant end was closed, i.e. for loop resistance resting, or open for insulation testing, and this resistance is known as the characteristic resistance of the circuit. Thus the characteristic resistance of a circuit could be defined as its apparent

loop or insulation resistance when extended to an infinite length. It would be assumed that the conductor resistance and the leakage were uniformly distributed over its length.

(b) Loop resistance per mile

$$= \frac{175 \cdot 6}{10} = 17 \cdot 56 \text{ ohms.}$$

Leakage resistance per mile

$$= 20,000 \times 10 = 200,000 \text{ ohms.}$$

$$R_o = \sqrt{\frac{R}{G}}$$

where R_o = characteristic resistance in ohms.
R = loop resistance per mile in ohms.
G = leakance per mile in mhos.

Substituting values,

$$R_o = \sqrt{\frac{17 \cdot 56}{\frac{1}{200,000}}}$$

$$= \sqrt{17 \cdot 56 \times 200,000}$$

$$= \sqrt{3,512,000}$$

$$= 1874 \text{ (approx.).}$$

Ans. The characteristic resistance is 1874 ohms.

Figure 113 represents a land-line circuit containing five repeaters, A, B, C, D, and E. Each repeater introduces a loss of 4 db due to the differential transformer. The line loss between each repeater is as shown. If the input to A is −2 db and the output of each repeater is adjusted to + 10 db, show the gain of each repeater. What is the total loss in the circuit between points x and y, and what is the overall gain?
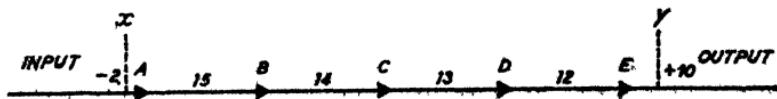

Fig. 113.
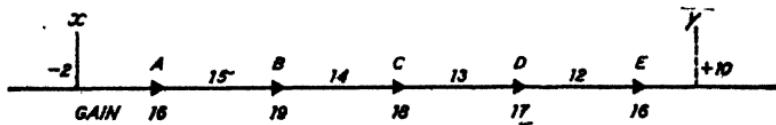
FIG. 114.

Fig. 114 shows the respective gains of the repeaters A,B,C,D, and E in order to give an output of 10 db at each repeater.

The total loss between x and y is the sum of the line and transformer losses, thus total loss = $(4 + 15) + (4 + 14) + (4 + 13) + (4 + 12) + 4 = 74$ db.

The overall gain is the difference between the output at E and the input at A. Overall gain = $+ 10 - (-2) = 12$ db.

Ans. The total loss in the circuit is 74 db. and the overall gain 12 db.

Write a short account of the use of the term "decibel." What is the advantage of expressing the transmission loss or gain in a circuit in decibels, over its expression in ratios only.

When current, either D.C. or A.C., is transmitted over a line, the power received at the distant end may be only a fraction of that sent, due to the various characteristics of the line. The power is said to have been attenuated. Where speech currents are concerned this effect is due mainly to the conductor resistance and the capacitance between the two wires. The unit in which this loss is expressed is termed the decibel. The power loss in decibels is expressed as 10 times the logarithm to the base 10 of the ratio of the power sent to that received, i.e.

$$\text{Loss in decibels} = 10 \ Log_{10} \frac{P_s}{P_r}$$

If a loss of, say, 3 decibels occurs in one part of a circuit and there is a loss of 7 decibels over the remainder of the circuit, the total loss is the sum of the two individual losses, namely, 10 decibels. Thus the total loss on any circuit consisting of a number of links

can be found very quickly if the losses in the various links are known in decibels. Besides a loss, a gain, such as that obtained through an amplifier, can be expressed in decibels.

The loss or gain in a circuit could be expressed purely as a ratio of the power sent to that received, e.g. if 1 milliwatt was sent and 0.002 milliwatts were received the loss could be expressed as $\dfrac{1}{0.002}$ or 500:1. If this ratio were applied to one section of a circuit only and there were several sections to be considered, it would be necessary to multiply together the ratios obtained. This may result in laborious calculations, whereas if the individual loss in each section is expressed as a logarithm, simple addition only is required to obtain the total loss.

What is the relationship between the neper and the decibel?

Both the neper and the decibel are units of attenuation, the former having the disadvantage of involving the use of natural logarithms, or alternatively common logarithms with a conversion factor. The decibel, however, is a smaller unit and involves the use of common logarithms only. It therefore becomes necessary to be able to convert nepers to decibels or vice versa.

Let x = number of decibels in one neper.

The attenuation in decibels = $x \times$ attenuation in nepers

But attenuation in decibels = $10 \, log_{10} \dfrac{P_s}{P_r}$

Where P_s = power sent.
and P_r = power received.

Also, attenuation in nepers =

$\tfrac{1}{2} \, log_e \dfrac{P_s}{P_r}$ or $\tfrac{1}{2} \, 2 \cdot 3026 \, log_{10} \dfrac{P_s}{P_r}$

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Therefore $10 \, log_{10} \dfrac{P_s}{P_r} = x \times \tfrac{1}{2} \times 2 \cdot 3026 \, log_{10} \dfrac{P_s}{P_r}$

and $10 = \dfrac{x \times 2 \cdot 3026}{2}$

$\therefore \; x = \dfrac{10 \times 2}{2 \cdot 3026} = 8 \cdot 686$

Ans. There are $8 \cdot 686$ decibels in 1 neper.

Calculate the total attenuation in (a) nepers, (b) decibels if the ratio of sent current to received current is (i) 50/1, (ii) 25/1, (iii) 2/1. What is the ratio between the power sent and power received in the case of a line having a total attenuation of 5 decibels?

Attenuation in nepers $= 2 \cdot 303 \, log_{10} \dfrac{I_s}{I_r}$

Attenuation in decibels $= 20 \, log_{10} \dfrac{I_s}{I_r}$

(I)   If $\dfrac{I_s}{I_r}$ $= 50$

Attenuation $= 2 \cdot 303 \, log_{10} \, 50$ nepers
$= 2 \cdot 303 \times 1 \cdot 699$
$ = \underline{3 \cdot 91 \text{ nepers}}$
$= 20 \times 1 \cdot 699$
$ = \underline{33 \cdot 98 \text{ decibels}}$

(II)   If $\dfrac{I_s}{I_r}$ $= 25$

Attenuation $= 2 \cdot 303 \, log_{10} \, 25$ nepers
$= 2 \cdot 303 \times 1 \cdot 3979$
$ = \underline{3 \cdot 22 \text{ nepers}}$
$= 20 \times 1 \cdot 3979$
$= \underline{27 \cdot 96 \text{ decibels}}$

(III)   If $\dfrac{I_s}{I_r}$ $= 2$

Attenuation $= 2 \cdot 303 \, log_{10} \, 2$ nepers
$= 2 \cdot 303 \times 0 \cdot 301$
$= 0 \cdot 693$ nepers
$= 20 \times 0 \cdot 301 = \underline{6 \cdot 02 \text{ decibels}}$

Attenuation	$= 10 \, log_{10} \dfrac{P_s}{P_r}$ decibels.
If Attenuation	$= 5$ decibels
then 5	$= 10 \, log_{10} \dfrac{P_s}{P_r}$

$$\therefore log_{10} \frac{P_s}{P_r} = 0\cdot5$$

$$\therefore \frac{P_s}{P_r} = 10^{0\cdot5}$$

$$= 3\cdot162$$

$$\therefore \frac{P_s}{P_r} = 3\cdot162:1$$

Ans. (I) 3·91 nepers, 33·98 decibels.
 (II) 3·22 nepers, 27·96 decibels.
 (III) 0·693 nepers, 6·02 decibels.

The ratio of power sent to power received

$$\frac{P_s}{P_r} = 3\cdot162/1$$

If one watt is applied at the sending end of a circuit and 0·25 watt is delivered at the receiving end, what is the power loss expressed in (1) nepers (2) decibels?

Let P_s and P_r be the power at the sending and receiving ends respectively and I_s and I_r the corresponding currents, then, assuming that the current at the sending and receiving end is flowing into equal impedances:

$$\frac{P_s}{P_r} = \frac{I_s^2 R}{I_r^2 R}$$

$$\therefore \sqrt{\frac{P_s}{P_r}} = \frac{I_s}{I_r}$$

and the loss in nepers $= log_e \dfrac{I_s}{I_r}$

$$= \tfrac{1}{2} log_e \frac{P_s}{P_r}$$

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$$= 2 \cdot 303 \times 0 \cdot 5 \, log_{10} \frac{1}{0 \cdot 25}$$

$$= 0 \cdot 63 \text{ Nepers.}$$

Loss in decibels $= 10 \, log_{10} \dfrac{P_s}{P_r}$

$$= 10 \, log_{10} \frac{1}{0 \cdot 25}$$

$$= 6 \cdot 02 \text{ decibels.}$$

Ans. (I) The power loss $= 0 \cdot 693$ nepers.
      (II) The power loss $= 6 \cdot 02$ decibels.

It has been found necessary to accommodate the operators of wireless telegraph channels in a building remote from the actual transmitter and receiver blocks.
How may remote control of transmitters and remote reception be achieved?

Remote control of transmission and remote reception may be effected over physical circuits set up between the operators' positions and the transmitters and receivers.

The type of circuit and terminal apparatus employed depends on the signalling conditions required, a few examples of both remote control transmission and remote reception are detailed below.

(a) Remote control of transmitters.

The most common methods adopted for remote control of a transmitter are:
      (1) Direct current keying via a telegraph relay.
      (2) Tone keying.

(1) Direct Current Keying.

The circuit arrangements are illustrated in Fig. 115 *(a)*. Operation of the telegraph key connects an earthed battery to the physical line which in turn operates the telegraph relay. The relay contacts are connected to the transmitter in place of a local telegraph

TRANSMITTER BLOCK   OPERATOR'S POSITION

PHYSICAL LINE
OR V.F CHANNEL   TELEGRAPH KEY

(a)

TELEGRAPH KEY

PHYSICAL PAIR   AUDIO
OSCILLATOR

(b)

RECEIVER BLOCK

(c)

OPERATOR'S TELEPHONE
RECEIVER

TELEGRAPH
RELAY

TELEGRAPH
RELAY

AUDIO FREQUENCY
OSCILLATOR

(d)

TELEGRAPH
RELAY

SOUNDER

(e)
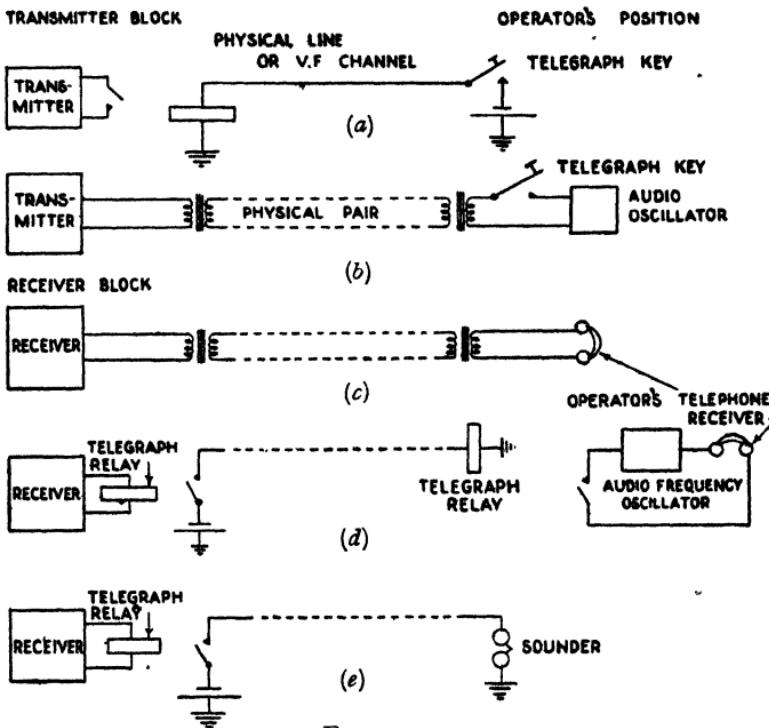
FIG. 115.

key.   A two-wire line may be used instead of a single wire and earth return if desired.

(2) *Tone keying.*

The audio-frequency tone used to modulate the transmitter is generated near the operators' position, the keyed tone being extended via a two-wire line to the transmitter.   If necessary line transformers and amplifiers may be installed.   Fig. 115 (b) shows the circuit arrangements.

(b) *Remote Control Reception.*

The method used to link up the receiving operator with the receiver is usually one of the following:

(1) Direct tone reception.
(2) Indirect tone reception.
(3) Sounder reception.

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(1) *Direct Tone Reception.*

The audio output of the receiver is passed via a two-wire line to the operating position. If necessary line-transformers and amplifiers may be incorporated. See. Fig. 115 (c).

(2) *Indirect Tone Reception.*

The receiver output is utilised to operate a telegraph relay the contents of which connect a D.C. potential to the physical line. At the operators' position, line current operates another telegraph relay, the contacts intercepting the circuit of an audio-oscillator and telephone receiver. The arrangements are illustrated in Fig. 115 (d).

(3) *Sounder Reception.*

As for indirect tone reception, the receiver output operates a telegraph relay which applies D.C. to the physical line. At the operators' position the incoming current operates a sounder either directly or via a relay. See Fig. 115 (e).

The single-wire line and earth return of Figs. 115 (d) and (e) may be replaced by a two-wire line.

Describe a method whereby a Wireless Telegraph link may be operated at a speed far in excess of that obtainable with hand-operated Morse Keys.

Show how the W/T Transmitter may be controlled from a remote W/T Office.

One method of increasing the signalling speed of a W/T link is by the utilisation of an automatic Morse transmitter and some form of Morse recording device. An automatic transmitter is essentially a power-operated Morse key, Morse signals fed into the transmitter in the form of perforations on a paper tape or slip being converted into electrical impulses. Motive power to drive the transmitter is generally obtained from a small electric motor.

There are various types of recording device suitable for the reception of high-speed Morse signals, the simpler types being (a) the Undulator and (b) the

Siphon Recorder. Both of these receivers record the Morse signals as an irregular ink line on a paper slip drawn by an electric motor beneath a pen controlled by the wireless receiver output.

Another form of receiving device is the Receiving Re-perforator which perforates a paper slip (similar to the one fed into the Auto-transmitter) in accordance with the received signals. This perforated slip is then fed through a Morse Printer which produces a typed copy of the message on either a paper tape or a page.
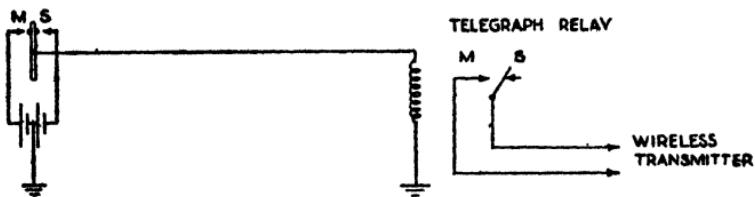

FIG. 116.

Fig. 116 shows how an auto-transmitter may be used to control a W/T transmitter remote from the operating position.

The electrical signals produced by the auto-transmitter are made to operate a telegraph relay in the transmitter building, the relay contacts taking the place of a local Morse key.

The R/C circuit may be operated on either a single or double current basis.

Describe with the aid of a simplified diagram the operation of a Wheatstone Automatic Morse Transmitter.

Fig. 117 illustrates the essential elements of a Wheatstone Transmitter suitable for Morse Code signals.

The transmitter mechanism is controlled by a paper slip perforated in accordance with the following code:

(a) Dot—One central hole and two larger holes, one above and one below the central hole.

(*b*) Dash—Two centre holes and two larger holes, one above the first centre hole and one below the second.

(*c*) Interval—One centre hole.
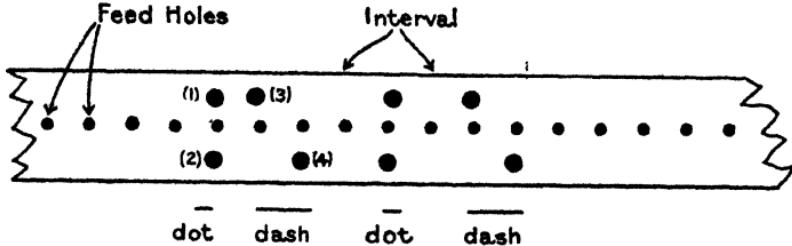
FIG. 117.

A sample of perforated slip is shown in Fig. 118.

Power to drive the transmitting mechanism and the paper feed is generally obtained from a fractional horse-power electric motor although earlier models were powered by gravitational force on a descending weight.

The transmitter consists essentially of two bell-crank levers $L1$ and $L2$, pivoted as shown, which in the absence of slip are held against pins $P1$ and $P2$ by the action of springs $S3$ and $S4$. Pins $P1$ and $P2$ are mounted on a rocker R which is caused to oscillate when the transmitter is running by the action of the rotating wheel W and its associated rod.

When $P1$ rises and $P2$ falls, rod $A1$ pivoted to $L1$ moves to the right and rod $A2$ carried by $L2$ moves to the left. The collet $C1$ on $A1$ moves the transmitter tongue T over to make contact with S, *spacing* potential being transmitted to line.

Similarly, when $P1$ falls and $P2$ rises, collet $C2$ moves the transmitter tongue into contact with M, *marking* potential being applied to line.

The action of the transmitter tongue is speeded up by the jockey roller J, which by the pressure of a spring ensures rapid transit from one contact to the other.
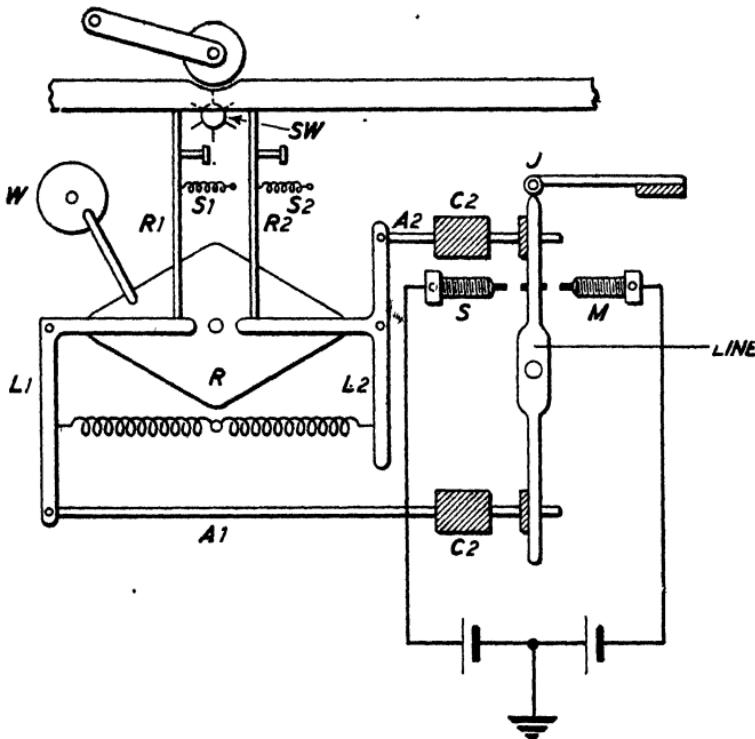
FIG. 118.

Rods $R1$ and $R2$ attached to bell-crank levers $L1$ and $L2$ respectively, are placed either side of a star wheel, SW, whose rotation is caused to move the slip through the transmitter. The speed of rotation of the star wheel is arranged so that the upward movement of $R1$ and $R2$ (if correctly adjusted) takes place when the perforations are exactly opposite the ends of the rods.

It will be seen that if the transmitter is run without slip, a continuous train of "marks" and "spaces", referred to as "reversals," will be sent to line, since rods $R1$ and $R2$ may rise and fall without hindrance.

However, when perforated slip is fed forward by the star wheel, rods $R1$ and $R2$ come into operation and prevent the movement of the associated bell-

cranks under the action of pins P_1 and P_2 unless a perforation permits R_1 or R_2 to pass through. In the absence of perforations the transmitter's tongue does not move.

Suppose a dot passes over the star·wheel, rod R_2 rises and is free to pass through hole (1) (Fig. 118) and C_2 moves T over to M; when P_1 rises, R_1 is free to pass through hole (2) and C_1 restores T to the spacing contact S. A dot has been transmitted.

Suppose the next signal is a dash, R_2 will pass through hole (3) when P_2 rises, but when R_1 rises there is no hole opposite its end thus the mark continues to be transmitted until the next time P_1 rises, when R_1 is free to pass through hole (4) and T returns to the spacing contact. A dash, three times the length of the dot, has been transmitted.

Rods R_1 and R_2 move forward slightly on entering a perforation in the moving slip, but springs S_1 and S_2 restore them.

### Describe with the aid of a circuit diagram the operation of the Creed High Speed Morse System.

The Creed High-Speed Morse System.

This system, which is a development of the Wheatstone automatic system, is particularly suitable for operation over long and difficult land lines and submarine cables, or for radio work. It provides a single channel over which messages are transmitted at high speed in the Morse code and recorded in printed Roman characters.

At the sending station the messages are prepared by as many operators as are necessary, each typing on a keyboard perforator which punches holes in a paper tape, representing signals in the Morse code. The perforated tape is then passed through a Creed automatic Morse transmitter. In this unit, two needles translate the perforations and cause currents to be transmitted to the line in the form of the well-known dot and dash signals of the Morse code. The

transmission speed may be 10 to 200 words per minute according to the volume of traffic and the limitations of the line.

At the receiving station the incoming high-speed signals are received and reproduced by a Creed Morse receiving re-perforator as perforations in a paper tape identical in every respect with the original tape prepared at the transmitting station. This tape is then passed through a Creed Morse printer which translates the perforations and prints the message in Roman characters on a paper tape or in page form, according to the type of printer used. Fig. 119 shows the arrangement of the apparatus.
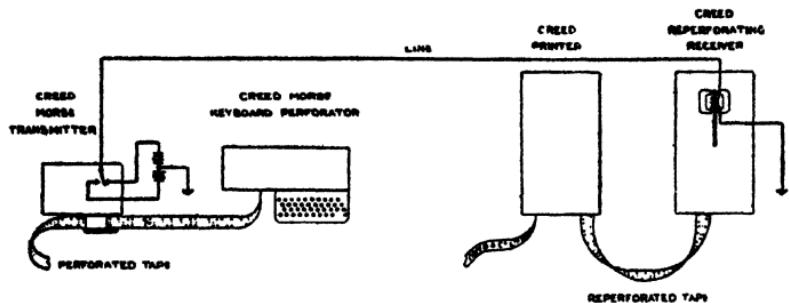
Principle of Creed High-Speed Morse Printing
Telegraph System

FIG. 119.

The paper received from the re-perforator may, of course, be used also for re-transmission.

The system can be operated on a simplex basis (one direction at a time) or a duplex basis (both directions simultaneously), and the speed of operation can quickly be adjusted to meet varying line conditions. Since it employs the Morse code, the signals can be read by sight or sound.

The Morse tape printer will work satisfactorily at a speed of 120 words per minute, but 100 words per minute may be considered a reliable speed for continuous use. The Morse page printer may be operated at 80 words per minute with safety.

Accurate synchronism between the machines at each end of the line is not necessary as the receiving re-perforator provides a sufficient margin of correction to allow of considerable differences in speed.

Application to Radio.

The Creed High-Speed Morse Transmitter is operating with conspicuous success on radio services, the signals being received by means of undulators. The R.M.S. *Queen Mary* is equipped with two transmitting sets and one undulator, transmitting and reception speeds of 100 w.p.m, have been obtained.

The tape transmitter controls a highly insulated polar relay, the contacts of which control one of the grid circuits of the radio transmitters.

Describe the operation of an Undulator, illustrating your answer with a simple diagram.

The Undulator is a form of siphon recording instrument.

A paper slip is arranged to be drawn over rollers by a small electric motor beneath a silver style-pen connected to an ink supply, the pen being moved at right angles to the direction of motion of the slip on receipt of "marking" signals. A sample of the trace produced on the slip is shown in Fig. 120.


dash   dot   dash   dot
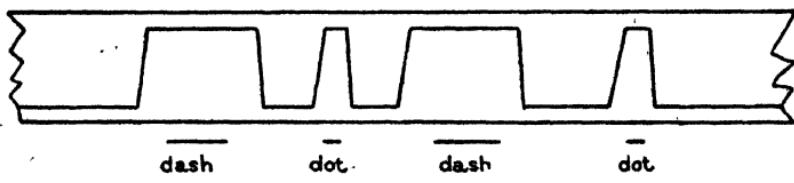
FIG. 120.

The silver style-pen (*SP*) has a longitudinal hole which is connected by a fine rubber tube to an ink reservoir.

The style is constructed to be rigid laterally, the free end being bent over to touch the slip with little

pressure. The opposite end of the style is attached to pivoted rod (*R*) which also carries two magnetic tongues (*T*), these tongues being polarised by a permanent magnet (*PM*).

The signalling current passes through the two operating coils (*C*), their magnetic effect deflecting the tongues and style in accordance with their direction.

The adjustable buffers (*B*) are fitted to limit the tongue travel, thus preventing damage to the style. The operating coils are fitted with adjustable pole pieces to facilitate adjustment.
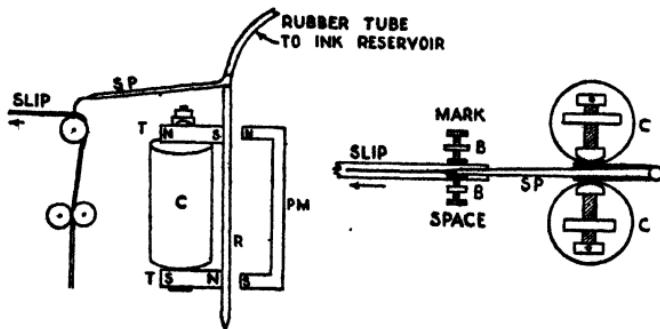
FIG. 121.

In practice the position of the trace on the slip (spacing) is adjusted so that there is approximately one-third of the width of the slip on the spacing side of the trace. Receipt of marking current rapidly deflects the style to the marking buffer, returning it to the spacing buffer at the end of the mark.

By fitting a variable speed control to the motor, the velocity of the slip may be adjusted to give maximum legibility of signals.

The main elements of the undulator are shown in Fig. 121.

MEASURING INSTRUMENTS

Sketch and describe the moving-coil ammeter.

Figs. 122 (*a*) and (*b*) show the essentials of a good type moving-coil galvanometer. The coil is wound upon an aluminium former which is pivoted so that it may rotate in the magnetic field of a permanent magnet. A soft iron core intensifies the field in
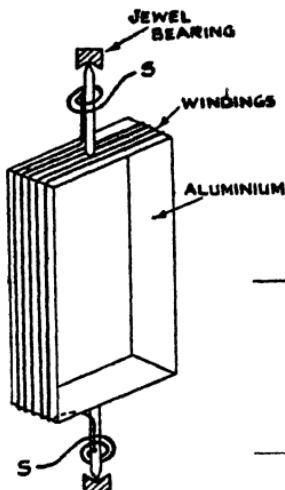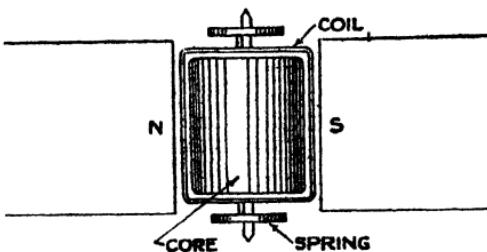
FIG. 122 (*a*).   FIG. 122 (*b*).

the air gap and also makes the field radial at all points within the movement range of the coil, affording a linear scale. An E.M.F. applied to the coil produces turning moment about the pivot, this is opposed by the torque of a pair of helical hair springs, which are so designed that when the pointer is at zero the torque due to one spring balances that

of the other. When a deflection occurs, however, the torque of the spring increases in direct proportion to the angle through which the coil is turned. The hair springs carry the current into and away from the coil. Fig. 122 (*a*) is enlarged to show the movement clearly.

Sketch and describe two methods by which a moving-coil ammeter could be arranged to measure alternating currents.
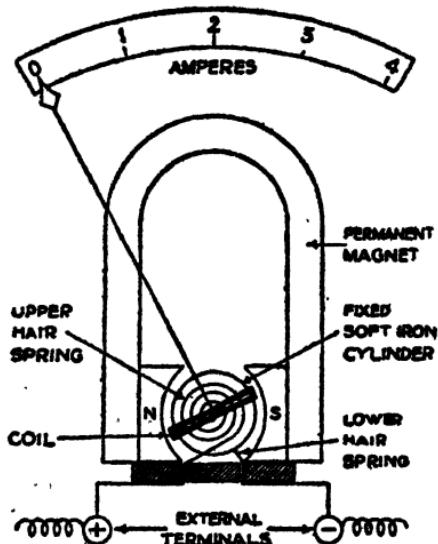
FIG. 123.

A moving-coil ammeter can be arranged to measure an alternating current by:

(1) Fitting a thermal-couple to the ammeter as shown in Fig. 123.

(2) Fitting a full-wave instrument rectifier as shown in Fig. 124.

(1) The thermal-couple consists of two wires of different material making contact at a definite point *B*. A current passes through the conductor *AC* and its temperature is increased. An E.M.F. is thus generated

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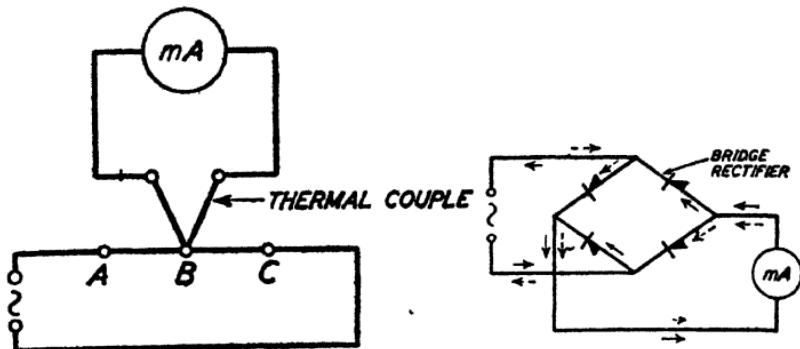
FIG. 124.

FIG. 125.

in the couple and a current passed through the milli-
ammeter.

(2) The bridge rectifier method of adapting moving-
coil instruments to measure alternating current is
shown in Fig. 125 and is utilised very considerably in
present-day practice.

The rectifier consists of four copper discs, approxi-
mately ½ in. diameter, each disc has a thin film of
oxide on one face. It is found that the disc of copper
with a coating of oxide acts as a rectifier, i.e. it offers
a low resistance to the flow of electricity in the direc-
tion from oxide to copper and a very high resistance
in the opposite direction. The four discs are con-
nected as shown in Fig. 125, each arrow representing
a disc and the direction of current flow. If the con-
ducting paths are traced out (with the aid of the arrows)
it will be seen that current flows unidirectionally
through the meter.

It will, however, be necessary to modify the scale
markings or recalibrate the moving-coil instrument as
the current flowing in each of the above cases will be
the mean and not the R.M.S. value.

*Describe with the aid of sketch the principle
of action of the moving-iron ammeter of the*

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***attraction type. Can this type of instrument
measure both alternating and direct currents?***

Fig. 126 shows the constructional details of the
moving-iron instrument.

When a current passes through the coil C the field
of force set up magnetises the soft iron disc which is
attracted towards the centre of the coil where the
magnetisation is greatest. In moving towards the
centre the needle attached to the soft iron disc is
deflected across the scale. The force acting on the
moving part depends upon the product:

(1) The degree of magnetisation of the soft iron
disc.

(2) The intensity of the magnetic field created.
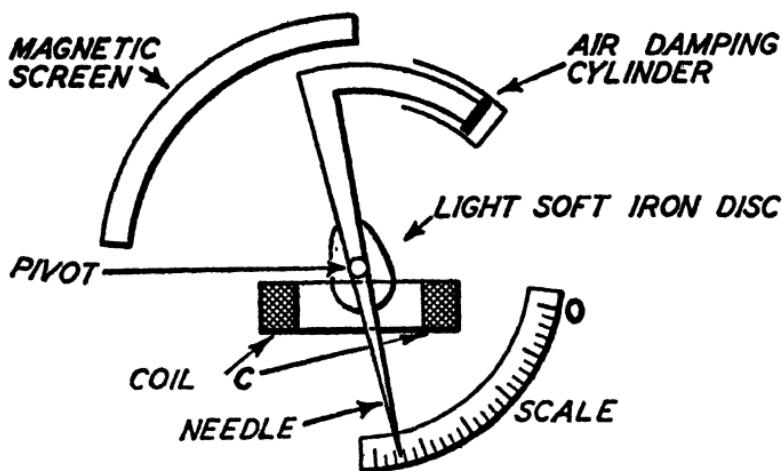

FIG. 126.

If the direction of the field is reversed both these
quantities change sign, and their product does not
change. The movement of the needle depends on the
square of the current i^2. If the current is reversed this
becomes $(-i)^2$ which is equal to i^2. This effect can
be looked at more simply as follows. Let us assume
that for a given current direction a given face of the

iron disc is magnetised "north," and is attracted by the magnetic field created by the current passing through the coil. When the current is reversed this field is reversed and would repel a north pole. At the same time the iron core is remagnetised so that the face previously magnetised "north" is now "south." An attraction therefore still results.

It follows, therefore, that the instrument can measure both alternating and direct current.

Describe with the aid of a sketch the principle of operation of the hot wire ammeter, and state the advantages, if any, that it possesses in comparison with the moving-coil ammeter.

The hot wire ammeter consists of a fine wire stretched between the terminals of the instrument *A* and *B*.
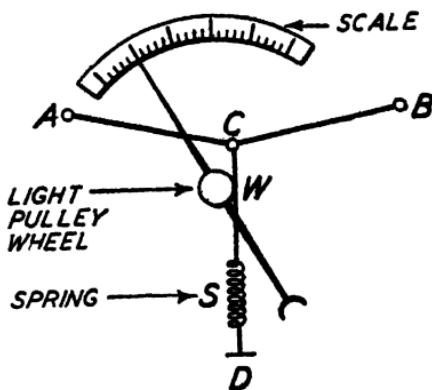
FIG. 127.

The middle point of this wire is held in tension by a fine wire that passes round a light pulley wheel to a spring *S*. If a current passes through wire *AB* it will become heated and slacken, this slack is taken up by the spring *S* pulling the fine pulley cord at *C*. In doing this the pulley wheel rotates and a needle which is pivoted to it is deflected across the scale.

The main advantage of this instrument over the

moving-coil type is that it is capable of measuring both alternating and direct currents, because its deflection is dependent upon the heating effects which are proportional to the square of the current flowing.

A moving-coil milliammeter has a resistance of 5 ohms and gives a full scale deflection with a current of 50 milliamperes. Giving a circuit diagram and particulars of any auxiliary apparatus required, explain how this instrument could be adapted to measure:

(a) A direct current of 5 amperes.
(b) A direct voltage of 20 volts.

The instrument could be adapted to measure 5 amperes by placing a resistance in parallel with it as
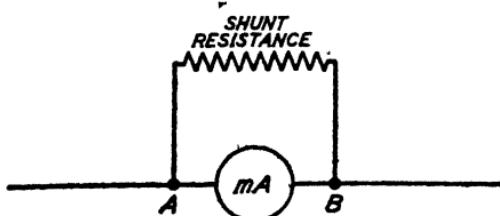
FIG. 128.

shown in Fig. 128, so that only a small proportion of the main current flows through the meter.

The value of this shunt resistance must be such that it carries 4·95 amperes from the available 5 amperes, thus permitting only 50 milliamperes to pass through the milliammeter. The value of the resistance can be ascertained by Ohm's Law, thus: P.D. across points $AB = I_1 r_1 = I_2 r_2$.

where I_1 is the current through the milliammeter.
I_2 is the current through the shunt resistance.
r_1 is the resistance of the milliammeter.
r_2 is the resistance of the shunt

$$I_2 r_2 = I_1 r_1.$$

$$\frac{50 \times 5}{1000} = 4 \cdot 95 r_2 \quad \therefore \ r_2 = \frac{50 \times 5}{1000 \times 4 \cdot 95} = \frac{1}{19 \cdot 8}$$

The shunt resistance = 0·0505 ohms.
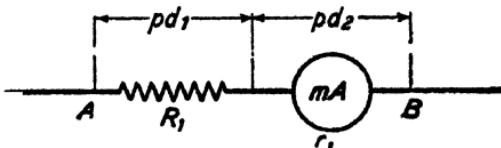
FIG. 129.

(b) The milliammeter could be arranged to measure a direct voltage of 20 volts by placing a suitable resistance in series with it as shown in Fig. 129, so that the combined potential drop across the resistance and the instrument is 20 volts. The value of the series resistance can be determined in the following manner.

Potential difference (P.D.) = $I \times R$.

The *PD* between points *A* and *B* (Fig. 129) is equal to $pd_1 + pd_2$ and equals 20 volts.

Where pd_1 is the drop across R_1 and pd_2 the drop across the milliammeter itself.

Thus 20 = $pd_1 + pd_2$
        = $IR_1 + Ir_1$

The current required to give a full scale deflection in the milliammeter is 50 milliamperes. Thus:

$$20 = \frac{50\,R_1}{1000} + \frac{50 \times 5}{1000}$$

$$= \frac{50\,R_1 + 250}{1000} \quad \therefore \ 20 \times 1000 = 50\,R_1 + 250$$

$$\therefore \ R_1 = \frac{20 \times 1000 - 250}{50} = \frac{19{,}750}{50} = 395$$

The value of the required series resistance is 395 ohms.

The resistance of the moving-coil system of a combined ammeter and voltmeter is 10 ohms, and a full-scale deflection is obtained when a current

of 10 milliamperes passes through the coil. Calculate the value of the resistance which would be required, in each case, to make the full-scale readings represent: (a) 2·5 volts, and (b) 50 milliamperes, state how each resistance should be connected.

Case (*a*) The resistance should be placed in series with the moving-coil system, and should be such that the voltage drop across the combination equals 2·5 volts.

Thus $I \times (R + r) = 2 \cdot 5$.   Where R is the series resistance.

$$\frac{10}{1000} \times (R + r) = 2 \cdot 5$$

r is the resistance of the moving coil system.

$$\therefore R + r = \frac{2 \cdot 5 \times 1000}{10} = 250$$

$$\therefore R = 250 - 10 = \underline{240 \text{ ohms.}}$$

If the meter is to be used as an ammeter, with a full scale deflection of 50 milliamperes a suitable parallel or shunt resistance must be placed with the moving system such that 40 milliamperes pass through the shunt and 10 milliamperes through the moving system. Now the P.D. across any parallel combination is the same as the P.D. across any one of the resistors.

Bearing this in mind:

$$PD = Ir$$
$$= 0 \cdot 01 \times 10$$
$$= 0 \cdot 1 \text{ volts.}$$

This is also the *PD* across the shunt resistance R

$$\therefore 0 \cdot 1 = I \times R$$
$$0 \cdot 1 = 0 \cdot 04 \times R$$

and $R = \dfrac{0 \cdot 1}{0 \cdot 04} = 2 \cdot 5$ ohms.

Ans.   (*a*) Series resistance of 240 ohms required.
     (*b*) Shunt resistance of 2·5 ohms required.

Explain with the aid of a simple diagram how a moving-coil instrument is enabled to read resistance values directly.

Fig. 130 gives a simple diagram of an "ohmmeter," a moving-coil instrument capable of measuring resistance values direct. The instrument incorporates a primary battery (usually 1·5 volts for resistance measurement up to, say, 100,000 ohms. The voltage of the battery must be increased if resistances above this value are to be measured accurately. A standard resistance R_s
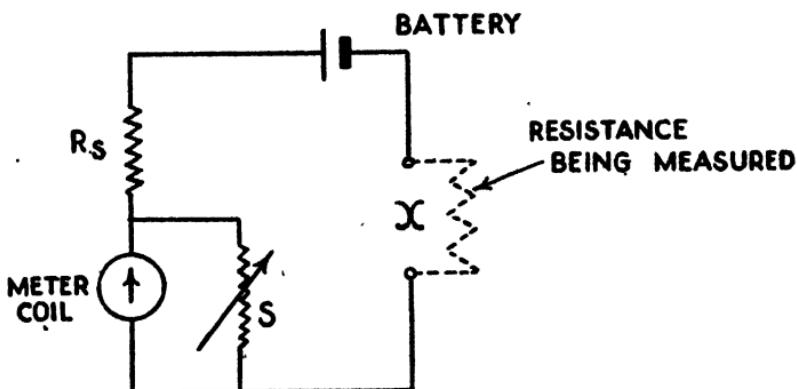
CONNECTIONS OF AN OHMMETER

FIG. 130.

has a value equal to the mid-scale reading of the instrument and a shunt resistance S is wired in parallel with the moving coil to provide a means of zero setting the instrument before making a resistance measurement. This feature is necessary to compensate for voltage variations of the battery with age. Zero setting is achieved by short circuiting the terminals x and adjusting S to obtain a full-scale deflection.

With terminals x short-circuited the current flowing $I = \dfrac{E}{R_s} \ldots$ (1) Remove the short circuit and connect

the resistance x to be measured. The current flowing under the conditions is $I = \dfrac{E}{R_s + x}$ ... (2) from (1) $E = I \times R_s$ and from (2) $E = I_1 (R_s + x)$.

The voltage of the battery E has remained constant throughout so

$$I_1 (R_s + x) = I R_s$$
$$\text{and} \quad R_s + x = \frac{I R_s}{I_1}$$
$$\therefore x = \frac{I R_s}{I_1} - R_s = R_s \left(\frac{I}{I_1} - 1 \right)$$

from which it will be seen that the result depends upon R_s (which is fixed) and the ratio of the two currents.

As the actual values of current are therefore immaterial it is allowable to use the variable shunt, as described for bringing the needle initially to full deflection (zero on the resistance scale) whatever the voltage may be. The second deflection with the resistance to be measured in circuit, is then a measure of its resistance. Some multi-range ohmmeters are capable of measuring resistances up to 2 megohms, in this case a 16-volt battery is usually used.

Sketch and describe the action of a simple type of Electrostatic Voltmeter. State for what purpose this particular instrument is suitable. Mention the merits of this type of voltmeter.

The electrostatic voltmeter is specially designed to measure high A.C. or D.C. voltages or potentials such as often occur between the plates of a condenser. The instrument consists of a number of fixed and movable plates. In its simplest form the instrument consists of two plates A and B (see Fig. 131) joined to a terminal T_1. A shaped vane C connected to terminal T_2 is pivoted at its centre and rotates between the plates A and B. Attached to C is a pointer P which moves across the graduated scale, and at its other end a hook (h) on which can be hung a weight.

If a voltage is applied to terminals T_1, T_2 a couple is set up which causes the movable vane to enter the space between the fixed vanes so as to increase the capacity of the condenser. The couple, which is balanced by the gravity effect of the weight on the hook (h), is proportional to the square of the applied potential difference, with the result The electrostatic voltmeter has two merits. The first is that the scale is non-linear.

FIG. 131.

that it does not draw a current from whatever potential difference is being measured, since its impedance is capacitive. The other advantage of the instrument is that it can be used equally well for A.C. or D.C. measurements, since its deflection is proportional to the square of the voltage which is always a positive quantity. In this respect it is similar to the moving-iron ammeter. When the instrument is used with a suitable multiplier there is practically no upper limit to the voltage which may be measured.

Enumerate the requirements of a good valve voltmeter.

The requirements of a good valve voltmeter are:
(1) Accuracy.
   (a) The deflection must be independent of frequency within the range of the instrument.
   (b) The deflection must be independent of waveshape unless discrimination between waveforms is specifically desired, as in peak and mean voltmeters.
(2) As nearly as possible infinite input impedance.
(3) Simplicity in handling the instrument.
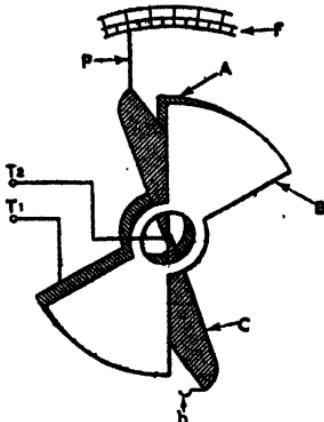
(4) Adequate protective devices in case a voltage above the range of the instrument is accidentally applied.

(5) The instrument should be robust.

(6) The instrument should be easily portable.

Give a circuit diagram and explain the action of a valve voltmeter.

How could the range of the instrument be increased?

A circuit diagram of a valve voltmeter capable of measuring radio-frequency voltages across components carrying a direct current is shown in Fig. 132.
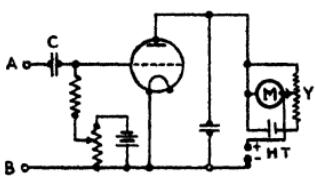
FIG. 132.
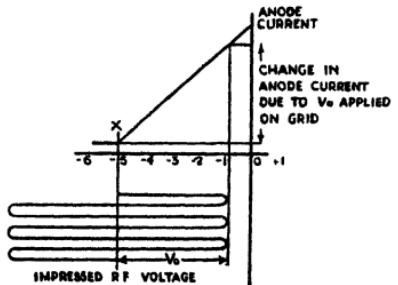
FIG. 133.

The R.F. voltage to be measured is applied across points A and B; the condenser (C) prevents any direct current reaching the grid of the valve but offers a negligible impedance to radio-frequency currents.

The valve is made to work on the bottom bend of its anode current grid volts curve (Point X in Fig. 133 by adjusting the grid bias voltage by means of a potentiometer (P).

The small steady anode current flowing through meter M with no H.F. input is balanced out by means of a battery and adjustable bridge arrangement (Y).

A radio-frequency voltage impressed on the grid causes an increase of anode current, as shown in Fig. 132. This change in anode current is shown on meter

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M which can be calibrated to read directly the H.F. volts applied to the grid.

The voltage range could be increased by means of a potentiometer, connected as shown in Fig. 134. The radio - frequency voltages to be measured are applied

FIG. 134.

across X and Y, the valve voltmeter being applied across A and B. The position of the tapping A will be determined by the relative amplitudes of the R.F. voltage and that which the valve voltmeter is capable of measuring, thus if the applied radio-frequency voltage is twice that giving a full-scale deflection of the valve voltmeter the point A should be a centre tap on the resistance R. The voltage drop across R_1 will be IR_1 (I being the current flowing through the potentiometer) which in this case is $IR/2$ since $R_1 = R/2$. The voltage drop across R is IR, the voltages across XY and AB will therefore be in the proportion of 2 to 1 and any reading on the valve voltmeter will have to be multiplied by 2 to obtain the actual voltage applied across XY. Other multiplying factors can be obtained by tapping off resistance R at suitable points.

Sketch and describe the action of the Megger. For what purpose is this instrument used.

The megger consists of a direct current generator, hand or motor driven and fitted with a slipping clutch, and a moving double-coil instrument contained in a single case. The general arrangement is shown in Fig. 135.

The current coil moves in the uniform magnetic field in the spaces between the fixed soft iron core and the pole pieces, and a current passing through it, tends to turn it in a clockwise direction. A current through the pressure coil (which is mechanically attached to the
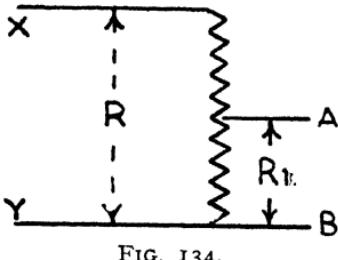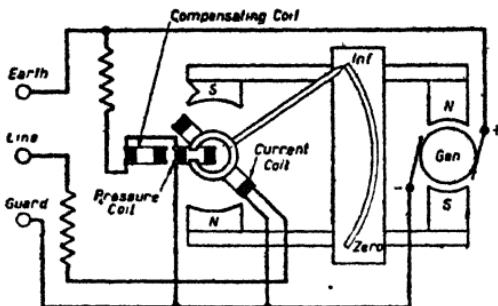
Fig. 135.

current coil) urges it in the opposite direction with a force proportional to the E.M.F. and to the distance through which the coil is turned. The position which the pair of coils takes up depends upon the ratio existing between E and I, i.e. upon the resistance of the circuit, and the pointer attached to the coils moves over a scale marked in ohms.

The megger is particularly suitable for measuring resistors having values above 10,000 ohms. It is also used for measuring the insulation resistance of components such as condensers, coils, transformers, etc.

Sketch and describe the action of a simple resonance type of wavemeter. What precautions should be taken to ensure accuracy?

Fig. 136 shows one simple form of resonance wavemeter. It consists of an inductance coil and condensers, a contact rectifier and headphones. Alternatively the rectifier and headphones can be replaced by a radio-frequency milliammeter or other suitable device. To obtain the wavelength of a transmitting station the wavemeter is tuned to resonance by means of the inductance and variable condenser. Resonance is indicated by maximum sound in the headphones or maximum current flowing when a radio-frequency milliammeter is used as the detector. Loose coupling between the wavemeter and the transmitter is essential
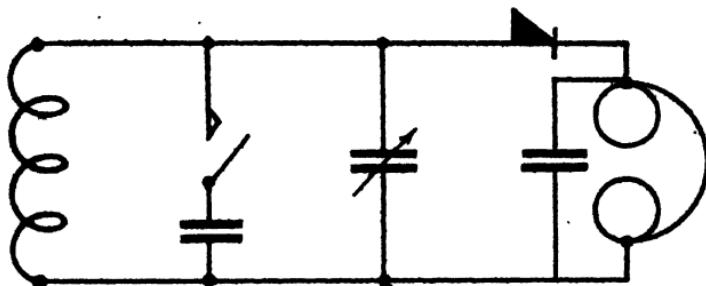
FIG. 136.

for accurate results. Furthermore, the wavemeter inductance coil should be kept well clear of all metal work. The instrument can be made to cover a wide range of wavelengths by utilising interchangeable inductance coils, or by the "switching-in" of an additional condenser as shown in Fig. 136.

Explain how, with the aid of a resonance wavemeter, a buzzer and an inductance coil the capacitances of two condensers can be compared.

One of the two condensers, C_1, is connected in parallel with the inductance coil L to form an oscillatory circuit, and an oscillation is set up in this by the buzzer. The wavemeter is then loosely coupled to the tuned circuit LC_1 and the wavelength λ_1 of the oscillation measured. The condenser C_1 is then replaced by the second condenser and the wavelength λ_2 of the tuned circuit again ascertained by means of the wavemeter.

From the standard formula $\lambda = 1885\sqrt{LC}$ it will be seen this λ varies as $\sqrt{C}$.

Then $\lambda_1 : \lambda_2 :: \sqrt{C_1} : \sqrt{C_2}$.

and $\dfrac{\lambda_1}{\lambda_2} = \dfrac{\sqrt{C_1}}{\sqrt{C_2}}$

hence $\left(\dfrac{\lambda_1}{\lambda_2}\right)^2 = \dfrac{C_1}{C_2}$

and $C_1 = C_2 \left(\dfrac{\lambda_1}{\lambda_2}\right)^2$

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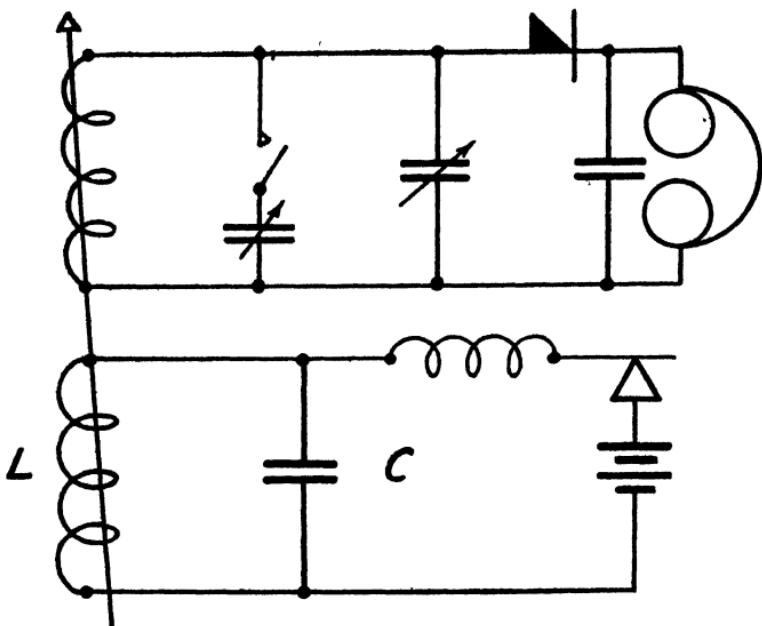
FIG. 137.

Describe the construction of an electrostatically deflected cathode ray tube. Explain how the light spot is obtained and how it may be caused to traverse the screen vertically and horizontally.

Fig. 138 shows the main constructional features of a modern cathode ray tube of the electron-deflected type. The electrodes are enclosed in the neck of a highly evacuated glass envelope, the inside of the circular end being coated with fluorescent material to form the screen. Electrode connections are brought through the end of the glass neck and secured in a pinch; the tube is generally fitted with a multi-pin base to facilitate external connections.

The electron beam is produced in exactly the same way as the electron stream of a thermionic valve by a directly or indirectly heated cathode (*C*). Surrounding the cathode is a metallic cylinder, the negative or
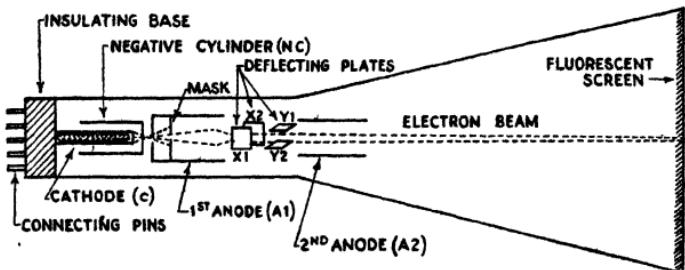
Wehnelt cylinder, which is maintained at a negative potential with respect to the cathode, concentrating the electron beam. The cross section of the beam is also reduced by the mask fitted into the end of the cylinder. The negative cylinder of the tube illustrated $(N.C.)$,also serves as the electrode for controlling the intensity of the electron beam (and thus the brightness of the light spot) although a separate auxiliary modulating electrode, or grid, is frequently introduced. This facility of modulating the electron beam is utilised in television reception to convert the vision receiver output into a replica of the original televised scene.

The electron beam leaving the hole in the mask of the Wehnelt cylinder enters the first anode $(A1)$ via a second mask, this and a further mask again limit the area of the beam. The anode is raised to a fairly high positive potential with respect to the cathode and accelerates the electron stream until it forms a high velocity beam, the velocity being maintained by the influence of the second anode $(A2)$ connected to a very high positive potential. The high-velocity electron beam streaming through the second anode strikes the screen on the end of the tube and the fluorescent material emits light. The size of the light spot depends on the cross sectional area of the electron beam and its brightness on the intensity and velocity of the electrons. A cathode ray tube operating as described above would produce a light spot in the centre of the circular screen, but it is possible to deflect the spot

into any position. Between the two anodes are fitted two sets of deflecting plates in mutually perpendicular planes along the electron stream, the plates are shown as (X_1), (X_2), (Y_1) and (Y_2).

The electron beam may be considered as an inertialess wire carrying current and will thus be deflected by an electrostatic field. If (Y_1) is made positive with respect to A_1, the beam will be deflected vertically upwards and if negative, vertically downwards. The deflection will be increased by connecting opposite
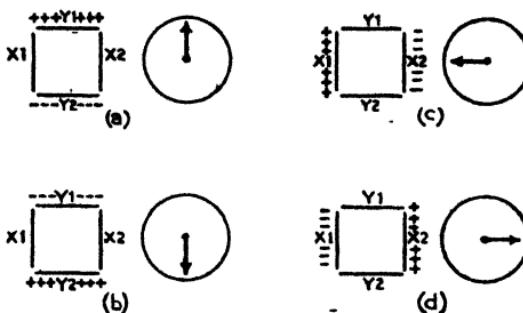
FIG. 139.

potentials to (Y_1) and (Y_2), with respect to (A_1). Similarly, deflection of the beam horizontally to the left or right may be accomplished by application of the deflecting potentials to the X plates. In each case the extent of the deflection will be directly proportional to the magnitude of the deflecting potentials. The process of beam deflection is illustrated in Fig. 139.

How may a cathode ray tube be utilised to examine the waveform of alternating potentials? Explain the function and operation of the Time Base circuit.

As described previously, the light spot produced by the electron beam of the cathode ray tube may be deflected into any position on the screen by application of suitable potentials to the deflector plates.

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Suppose an alternating potential be applied between plates Y_1 and Y_2. The light spot will trace out a vertical line whose length will be directly proportional to the peak positive and negative values. This display will convey no information about the waveform of the alternating potential. If the light spot is to trace out the waveform of the e.m.f. being examined, with respect to time, it must be moved horizontally across the screen, with time. This horizontal motion is effected by applying a further potential between plates X_1 and X_2. This potential, known as the time-base, has an adjustable frequency to permit examination of potentials at various frequencies. To obtain a clear display, the ratio of time-base frequency to the frequency of the potential under examination should be an exact multiple, a ratio of $1 : 1$ resulting in the display of a single cycle.

The standard form of time-base provides a slow forward movement and a very rapid backward movement or "fly back," i.e. the output of the time-base circuit will possess a "saw tooth" waveform.

Although the electron stream of the cathode ray tube is continuous, the extreme rapidity with which the "fly back" occurs prevents any perceptible effect on the display, except in cases where the time-base frequency is very high and the "fly back" time is comparable withthe time taken for the forward motion. Under such conditions the "fly back" may be observed as a faint horizontal line.

A typical time-base circuit suitable for use with an oscilloscope is shown in Fig. 140.

The time-base is obtained by charging a condenser (C)
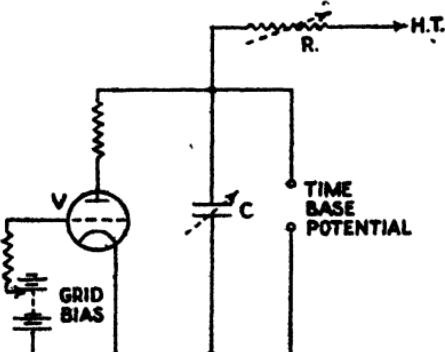
FIG. 140.

at a constant current through a high resistance (R), so that the potential across (C) increases linearly with time. The rate at which the potential rises will depend on the values of (C) and (R) (i.e. their time constant), and by making them both adjustable the time-base frequency will also be variable. To ensure that the potential rise across (C) is linear, it is usual to employ an H.T. voltage at least ten times the peak potential developed across (C), 1000 volts being desirable.

Across (C) is connected a gas-filled triode (V) which passes no anode current until the anode potential, with respect to the cathode, reaches a critical value determined by the grid bias, when the anode resistance drops to a very low value. The potential across (C)

FIG. 141.

will thus rise comparatively slowly until the critical value is reached, when (C) will be rapidly discharged, the valve become non-conducting once more, and a fresh cycle commence. As the discharge is controlled by the grid bias, the latter should be derived from a constant source, usually a separate power unit or battery.

The comparatively long charging time provides the slow scanning movement of the electron beam and the very short discharge time the rapid "fly back."

The "saw tooth" waveform of the time-base circuit output is shown in Fig. 141.

RADIO INTERFERENCE AND ITS SUPPRESSION

Write a short essay on Radio Interference.

Radio interference is the term usually applied to the many undesirable clicks, thumps, and whines, etc., produced by sources external from a wireless receiver, which frequently mar reception on broadcast wavelengths.

Radio Interference may .be sub-divided into two main categories, (*a*) Static interference; (*b*) Man-made interference.

Static interference, or as it is more commonly known, "atmospherics," is due to electrical disturbances of the atmosphere, most prevalent during periods of thundery weather, and during electrical storms.

Static interference is caused by lightning discharges between earth and cloud or cloud and cloud, and as the discharges only have a duration of a few milliseconds, they may be considered to consist of an infinite number of sinusoidal waves, the disturbance affecting reception over a very wide wavelength range. For this reason it is impossible to "tune out" atmospheric interference from a broadcast receiver.

The energy released by a lightning discharge is colossal and the electro-magnetic radiation produced may affect wireless receivers hundreds of miles distant from the source.

Static interference is most troublesome on the longer wavelengths (low frequencies), but gradually decreases with a rise in frequency until at very high frequencies i.e. ultra-short wavelengths, the effect is practically negligible.

Man-made interference is the general term applied to

all unwanted radio frequency disturbances produced by the operation of electrical plant. The most common sources of disturbances are:

(a) Ignition systems of motor vehicles and aeroplanes.

(b) Domestic and industrial electrical apparatus.

(c) X-ray, Ultra-violet ray and diathermy equipment.

Man-made interference may reach a radio receiver, either via the supply mains in the case of a mains-operated receiver or via the aerial and earth system, the latter affecting both battery and mains operated types.

Propagation of the interference is in the first instance by conduction through the supply mains, and in the second either by direct radiation or by re-radiation from a conductor, i.e. power or telephone lines, metallic objects, etc.

Man-made interference may affect transmissions on any wavelength between 5 and 2,000 metres, although disturbances caused by ignition systems and high-frequency apparatus are more pronounced at the higher frequencies.

Interference due to motor-cars and buses is normally only troublesome up to a range of several hundred yards, but at the other extreme, diathermy and X-ray apparatus has been known to affect receivers hundreds of miles distant.

How may atmospheric interference with broadcast reception be minimised?

The wave-form of atmospheric interference set up by lightning discharge is made up of a very large number of sine waves, thus the static interference will affect the whole of the broadcast waveband.

The obvious method of minimising the effect of static interference on a broadcast receiver is by reducing the acceptance frequency band-width of the tuned circuits to the limit compatible with the desired quality of reception.

In the case of wireless equipment designed specifically for the reception of telegraph transmissions, the acceptance bandwidth of the tuned circuits may be reduced to between 50 and 100 cycles per second without appreciably affecting the received signal.

A highly selective receiver of this type will be affected only by comparatively local lightning discharges, when the interference voltage reaching the detector is sufficiently large to materially affect the output.

As the successful reception of broadcast transmissions, more especially of music, requires the acceptance of a bandwidth of some 16 kilocycles (16,000 c.p.s.) it is impossible to reduce the "band pass" of a broadcast receiver very far below these limits without perceptibly impairing the quality of reproduction.

It will be appreciated that the interference voltage injected into a receiver having an acceptance bandwidth of some 16 kc/s. will be comparatively high even when the source of disturbance is remote from the receiver.

One method of minimising atmospheric interference at broadcast frequencies is by utilising a directional receiving aerial, and preferably a directional transmitting aerial in addition. Some improvement may be observed by using a simple rotating frame aerial for reception, but the most noticeable improvement is obtained on point-to-point radio links employing specially designed directional aerial arrays for transmission and reception.

A recent commercial development in the reduction of static interference has been a special form of automatic volume control. The high amplitude of the signal produced in the receiver by static disturbance is employed to produce a cut-off bias on the grid of one of the audio-frequency amplifiers.

Since the audio-frequency amplifier is biased to cut off, both the interference and the desired signal are suppressed for a period depending upon the duration of the static, but as this is extremely short the apparent continuity of the programme is unaffected.

***Operation of a mains-driven wireless receiver
installed in a steel framed building has been ren-
dered impossible by man-made interference.***

***Describe simple tests to determine the nature of
the interference.***

The radio interference reaching the receiver may be
one, or a combination, of the following types:

(*a*) Directly radiated interference.

(*b*) Re-radiated interference.

(*c*) Mains-borne interference.

Before entering into details of tests necessary to
typify the interference, let us first consider the con-
ditions under which interference propagated by each
of the above means, will reach the receiver.

Interference reaching the receiver by direct radiation
is introduced via the aerial or earth system, the ether
providing the conducting medium.

Re-radiated interference also enters the receiver by
way of the aerial or earth, but the ether does not form
the entire conducting path from the source. Radio-
frequency waves radiated by the offending electrical
equipment may be conducted by telephone wires,
power wires, or even steelwork used in construction
of buildings to a point in close proximity to the aerial
and earth system of the affected receiver, where re-
radiation takes place.

In a fairly large proportion of cases affecting mains-
operated receivers, the interfering radio frequencies
reach the receiver via the supply mains, the disturbing
apparatus injecting radio-frequency current into the
mains.

Returning to the receiver in question. To prove
that the interference is of either type (*a*) or (*b*) discon-
nect aerial and earth in turn, disappearance of the
disturbance indicating that interference is being
introduced.

If interference persists with both aerial and earth
disconnected and receiver moved as far as possible·

from any metallic objects it is almost certain that interference of type (*c*) is causing the trouble.

Differentiation between types (*a*) and (*b*) is slightly more difficult. After proving whether the aerial or earth is introducing the interference, erect an alternative temporary aerial or earth whichever is concerned, preferably one which can be readily moved about.

By making tests with the temporary aerial or earth in various positions it should be possible to determine whether the interference is being caused by direct radiation or by re-radiation from a nearby metallic object.

It is desired to erect a reasonably simple aerial system to cover a wave-range of 200-2000 metres which will be as free from man-made interference as possible.

Describe a suitable aerial.

What precautions may be taken to reduce the possibility of damage to receiving apparatus by natural electrical discharges.

The majority of man-made interference introduced into a wireless receiver by the aerial is picked up by the down lead thus to eliminate this source of disturbance the down lead should be screened. To improve the efficiency of an arrangement of this type, matching transformers are fitted at the junction of the down lead with the aerial and at the receiver.

The horizontal portion of the aerial should be erected as high as possible, 30 feet is sufficient, and have a length of from 25 to 50 feet.

The further away from buildings the horizontal portion is erected the less is the likelihood of interference being picked up from electricity supply wiring.

The wire used for the horizontal member should be multiple stranded copper either bare or insulated with weatherproof material. Toughened glass insulators should be employed for suspension as these maintain a high degree of insulation even when coated with soot, etc.

The earth connection is also of supreme importance. The best earth obtainable is a cold-water pipe provided connection is made on the street side of stop-taps and storage tanks. Failing this an earth connection should be obtained by burying a copper or galvanised iron plate having an area of some 3 to 5 square feet at a depth of several feet in damp soil.

In dry ground it is advisable to install a pipe so that the soil round the plate may be moistened.

The earth lead should be as direct as practicable. Fig. 142 illustrates the arrangements.

ENCLOSED SPARK GAP

AERIAL TRANSFORMER

AERIAL TRANSFORMER

REC EARTH

WATER PIPE
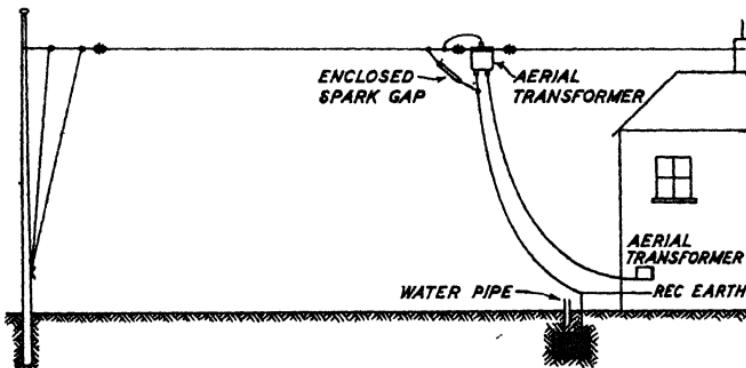
FIG. 142.

There are two methods of minimising the possibilities of damage to receiver equipment by lightning discharge. They are:

(1) The provision of a spark gap between the aerial and earth which will by-pass potentials set up in the aerial by static discharges.

(2) If reception is not required during thunderstorms, the aerial should be disconnected from the receiver and connected directly to earth by means of a suitable switch installed outside the building.

When using simple aerial systems the spark gap, normally of the open type is fitted outside the building at the point of entry.

The aerial system illustrated in Fig. 142 incorporates an enclosed spark gap connected as shown. In this position the spark gap affords protection for the aerial transformers in addition to the receiver.

It should be understood that no protector is completely "lightning proof" as a discharge in the immediate vicinity of an aerial is liable to destroy or severely damage both aerial and protector and on occasions the receiver too.

What method of suppression should be adopted to eliminate man-made interference propagated:

    (a) **By direct radiation.**

    (b) **By re-radiation.**

    (c) **Via the supply mains.**

Man-made interference whatever the means of propagation, should, if at all possible, be suppressed at the source.

Suppression is achieved by fitting specially designed radio-frequency filters to the interfering apparatus.

Radiation interference of types (a) and (b) is suppressed by connecting a radio-frequency acceptor network across the motor brushes, contactor, etc., giving rise to the disturbance.

To prevent injection of interference into the supply mains, a radio-frequency rejector network is connected in the supply lead as near as possible to the equipment.

If for any reason it is not possible to effect suppression of the radio interference at the source, steps can be taken to minimise the trouble at the receiver as follows:

Radiated interference of types (a) and (b) can be reduced by utilising an aerial with screened down lead as described in previous question.

Mains borne interference may be eliminated by insertion of a radio-frequency rejector network as near as possible to the receiver, in the mains supply lead.

***Electrical equipment in a large machine shop is
suspected of producing radio interference.***

***How, by means of simple apparatus, may the
source of the trouble be localised? Include a
brief description of suitable equipment.***

Before any tests are carried out in the machine shop
where the suspected apparatus is installed, an inventory of all equipment prone to produce radio-interference should be prepared.

Items such as electric fans, dust extractors, vacuum
cleaners, etc., should not be overlooked.

Interference other than that caused by motor
starters, etc., may be localised whilst the machinery
is in operation, thus testing apparatus which can be
used without interfering in any way with the machine
under test is to be preferred.

Suitable testing equipment consists of a reasonably
sensitive battery-operated portable receiver incorporating headphone output, and a test coil which
replaces the normal internal frame aerial. The test
coil operates as a loop aerial and by moving it into the
vicinity of the suspected apparatus any radio-frequency
radiation is picked up, producing audio-frequency
disturbance in the telephones.

The receiver may be of the "straight" or superheterodyne type, and may cover only medium and
long wavelengths, although inclusion of a third, short
waveband, is extremely useful for comparing interference over a wide wave range.

This comparison of the magnitude of interference at
widely varying frequencies greatly simplifies the design
of suitable suppressors.

Tests for interference in the machine shop should be
carried out systematically, each machine in the
inventory being checked and the results recorded.

When every item has been tested the test results
will indicate where the trouble lies, and suitable suppression action should be taken.

Interference set up by motor starters presents

slightly more difficulty, and to test each starter, the associated machine must be stopped, the test coil of the detector held in close proximity to the starter and the starter operated.

Several tests may be necessary before a definite decision can be made.

It has been found that medical diathermy apparatus produces a particularly virulent form of radio interference.
What precautions should be taken when constructing a new diathermy theatre?

A modern hospital diathermy equipment, when in operation, causes a radio-frequency current of several amps to flow through the patient.

The radio interference set up by the apparatus and its human antenna will, by direct and indirect radiation, affect wireless receivers considerable distances away.

The only effective method of eliminating the interference is to accommodate the entire apparatus, patient and attendants in a completely electrostatically screened room or cubicle. For the screening to be in the least satisfactory, every square inch of walls, ceiling and floor, including all windows and doors must receive very careful attention.

The methods of screening adopted when constructing a new theatre are different in several respects from those which would be used to screen an existing room. For the purpose of this answer the former methods only will be described.

The walls and ceiling may be effectively screened by incorporating close-meshed wire-netting in the plaster, great care being taken to bond the wire at joints and corners.

Linoleum-covered wooden floors may be screened by laying metal foil between the boards and the linoleum, whilst concrete floors may be dealt with by including a layer of close-meshed wire-netting in the concrete.

Both methods rely on very careful bonding for success.

Windows are frequently screened by utilising glass into which fine wire-netting has been introduced, the wire being brought out at the edges to permit connection to earth. Plain glass windows may be screened by erecting shutters of earthed fine wire-netting.

Doors need very special attention. They may be constructed entirely of metal or of wood lined with metal foil on the inside. They must be extremely well fitting, and should be bonded to the wall screening, at the hinge side by flexible conductors and the latch side by suitable contacts.

The most important point is that all screening must be carefully bonded together and connected to earth. Several different earthing points are to be preferred.

Screening will prevent direct radiation from the diathermy apparatus, but interfering radio frequencies might be conducted away from the theatre by the supply mains, electric light wiring, telephone wiring, bell and alarm circuits, etc., and then re-radiated from some other point. To guard against this eventuality, suitable rejector filters should be fitted at the points of entry of all these services.

When all screening and earthing has been completed all filters fitted and the diathermy apparatus installed tests should be carried out with a portable all-wave receiver to prove the effectiveness of the precautions taken.

Only on conclusion of successful tests should the theatre be brought into service.

Define the term filter, and hence enumerate the characteristics of four types of filter with which you are acquainted.

A filter is an electrical network so designed that the ratio of received current to sent current is as nearly as possible unity over a certain range of frequencies and negligibly low at other frequencies.

(1) *Low Pass Filter.*

A filter so designed that the ratio of received current to sent current is as nearly as possible unity below a certain frequency and negligibly low above that frequency.

(2) *High Pass Filter.*

A filter so designed that the ratio of received current to sent current is as nearly as possible unity above a certain frequency and negligibly low below that frequency.

(3) *Band Pass Filter.*

A filter so designed that the ratio of received current to sent current is as nearly as possible unity over a certain range of frequency and negligibly low above and below that range.

(4) *Band Rejection Filter.*

A filter so designed that the ratio of received current to sent current is as nearly as possible unity over and above a certain range of frequency and negligibly low over that range.

Draw a diagram of the arrangement of condensers and inductances for:

    (***a***) ***A low pass filter.***
    (***b***) ***A high pass filter.***
    (***c***) ***A band pass filter.***

What points would you consider important in the choice of condensers and inductances for an audio-frequency filter if a sharp cut-off is required?

Figs. 143 (*a*) (*b*) and (*c*) show the arrangement of condensers and inductances for the three types of filter.

The most important points to consider when choosing the components are:

Condensers. High insulation resistance between plates and between plates and casing. Condensers having mica insulation would be very suitable owing to their stability with temperature and age. The specified capacity values should be correct within close limits.
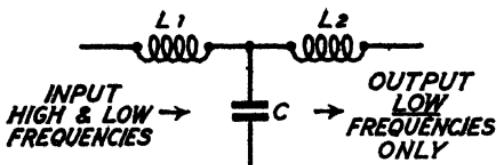
(a) LOW PASS FILTER
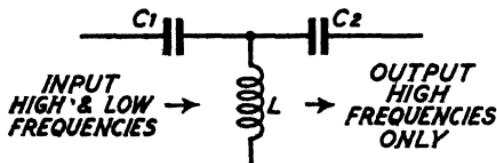
(b) HIGH PASS FILTER
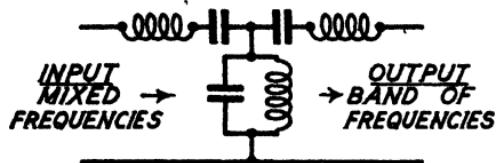
(c) BAND PASS FILTER

FIG. 143.

Inductances. Their $\frac{L}{R}$ ratio should be high. The specified values should be correct within close limits.

Describe the construction of suitable filters for the suppression of radio interference as follows:
    (a) Suppression of fractional H.P. single-phase motor.
    (b) Suppression of lift contactor.
    (c) Suppression at receiver, of mains-borne interference.

The filters usually found to be satisfactory for the suppression of interference set up by fractional H.P.
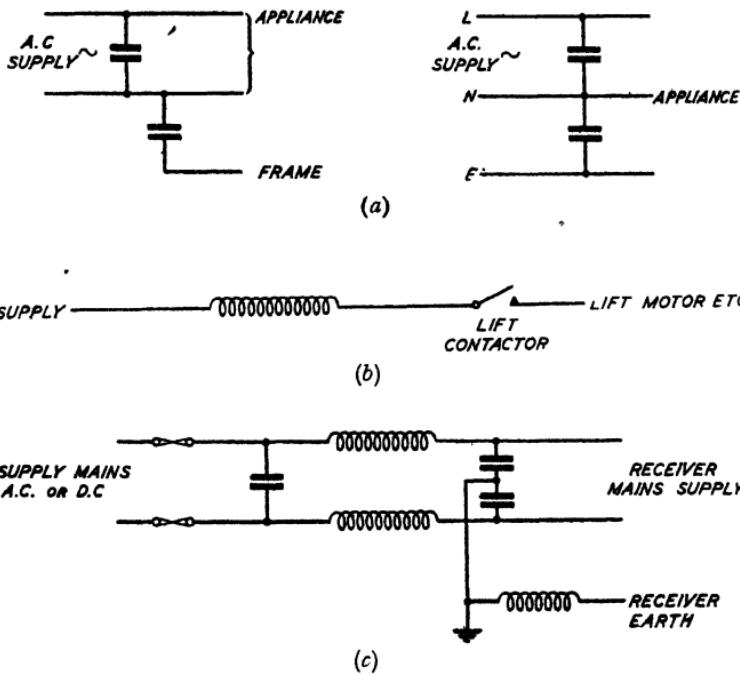
FIG. 144.

A.C. motors as used in vacuum cleaners, hair dryers and similar apparatus, are of the condenser type. In commercial form the filters are designed as self-contained units for connection in the flexible power lead as near as possible to the appliance, thus preventing radio frequency radiation from the lead.

The suppressors are constructed for two-wire and three-wire appliances, connections as shown in Fig. 144 (a).

(b) The elimination of radio interference caused by lift contactors is generally achieved by installation of a multiple suppressor in the contactor wiring, at a point as near as possible to the contacts.

The suppressor comprises of sufficient inductive filters to suppress all contactors of the lift controller.

Connections between suppressor and contactors

should be of lead-covered cable or run in conduit, an additional guard against radiation.

Fig. 144 (*b*) illustrates one contactor filter.

The suppressor fitted in the mains lead of a wireless receiver to prevent entry of mains-borne interference is a composite filter designed to be effective over the whole operating range of the receiver, 200–2000 metres for a normal broadcast receiver, 10–2000 metres for a receiver covering the short wave-bands.

The filter components are frequently contained in a small moulded case intended for mounting beside the receiver power point. A socket and plug is incorporated to permit connection of the suppressor by plugging the receiver mains lead into the unit and the plug associated with the suppressor into the power point. It is common practice to include low rated fuses in the unit to prevent damage to the filter components and receiver by accidental overload.

Connection of the filter components is shown in Fig. 144 (*c*).

No values have been quoted for the components used in the filters described above since these are determined by the frequency band over which interference is being experienced.

CHAPTER XII

MISCELLANEOUS (SPEECH ON LIGHT, AIRCRAFT LANDING)

Write a stage-by-stage commentary on the conversion of sounds produced in a broadcasting studio into a modulated electromagnetic wave. (Assuming the use of a moving-coil microphone.)

(*a*) The sounds produced in the broadcasting studio, voices, music, etc., consist of complex sound waves which impinge on the microphone diaphragm. The microphone consists of a very light diaphragm, attached to a light wire coil suspended in the intense annular magnetic field of a powerful permanent or electro-magnet.

(*b*) The action of the sound waves on the diaphragm is to cause the speech-coil to vibrate in unison with the waves.

(*c*) The movements of the speech coil in the magnetic field produces very small currents in the coil which vary directly in magnitude and frequency with the sound waves producing them.

(*d*) These speech currents are amplified by means of high-quality amplifiers and are conveyed by high quality land lines (music circuits), to the transmitter site.

(*e*) At the transmitter (which consists of a source of radio-frequency current or carrier current, a modulator and high-power radio frequency amplifiers), the amplified speech currents are imposed on the carrier current by means of the modulator.

(*f*) The transmitting aerial is energised by a modulated radio-frequency current and radiates electromagnetic waves modulated in accordance with the sound waves reaching the studio microphone.

Write a stage-by-stage commentary on the conversion of a modulated electromagnetic wave into sound.

Assuming the use of a transformer coupled 1-V-1 T.R.F. receiver and moving-coil loudspeaker.

(*a*) The electromagnetic wave reaches the receiver aerial which is tuned to accept the carrier wave and the sidebands carrying the intelligence.

(*b*) The electromagnetic waves produce very small, varying radio frequency currents in the receiver aerial circuit.

(*c*) These flow through the primary winding of a tuned radio-frequency transformer, the secondary winding of which applies a varying radio-frequency voltage to the grid of the radio-frequency amplifier. An amplified radio-frequency voltage is produced in the anode circuit of the valve.

(*d*) The amplified radio-frequency voltage is rectified by the detector valve, rectification separating the audio-frequency component from the radio-frequency carrier wave. Alternatively this process may be termed "demodulation".

(*d*) The audio-frequency component of the detector output passes through the primary winding of an audio-frequency transformer, the radio-frequency component being by-passed by a small fixed condenser.

(*f*) The output of the audio-transformer applies a varying audio-frequency potential to the grid of the audio-frequency amplifier, the anode current of the valve varying in accordance with the modulation impressed on the received electromagnetic wave, which in turn corresponds to the output of the broadcasting studio microphone. .

(*g*) The output from the audio-frequency amplifier passes through the speech-coil of the moving-coil loudspeaker, usually via a matching transformer. The action of the varying magnetic field set up by the audio-frequency currents flowing through the speech-coil, upon the intense magnetic field between the pole

pieces of the loudspeaker magnet, produces movements of the diaphragm or cone. These movements set up sound waves which correspond almost exactly to those reaching the microphone in the broadcasting studio.

Discuss the choice of wavelengths for the maintenance of a world-wide radio-telephone network from Great Britain.

The choice of wavelength for the maintenance of each link of a world-wide radio-telephone network from this country, is dependent on the geographical position of the country it serves.

Services between this country and European stations can be satisfactorily set up on wavelengths in the medium-wave commercial band. Transmission over these links is not liable to suffer daylight/darkness and seasonal variations as the ground wave only is utilised.

Satisfactory links between this country and more distant stations are usually confined to the short-wave bands, i.e. between 12 and 100 metres.

As transmission between these wavelength limits is subject to daylight/darkness and seasonal variations in the stratospheric reflecting layers, it is necessary to allocate several wavelengths to each link, the one least affected by prevailing conditions being used.

Daylight/darkness and seasonal variations in short-wave transmission are caused by changes in the angle of reflection of electromagnetic waves reaching the ionised stratospheric layers. The change of angle results in the reflected wave reaching the earth's surface in a different geographical position, thus the field strength of the signal received at a particular station, will vary.

The actual choice of wavelength for radio-telephone services to particular countries have been determined by practical tests over a number of years. A few of these results are indicated below:

(*a*) America   13; 18; 24; 34 metres.
(*b*) Canada   18; 24; 34; 44; 70 metres.
(*c*) South Africa   15; 20; 34; 40 metres.
(*d*) Egypt   20; 30; 44 metres.
(*e*) Australia   27; 32 metres.

A reliable 24-hour service between Great Britain and (*a*), (*b*), (*c*) and (*d*) is readily achieved, but services to Australia and similarly situated countries are often interrupted for considerable periods by severe adverse conditions.

Explain without diagrams one radio method by which an aircraft can land safely in foggy weather.

One method, "the lorenz landing system", employs two transmitters each of which transmits a narrow beam of signals. These two beams are made to overlap a few degrees along the safest line of approach to the aerodrome. One transmitter sends dots and the other dashes and transmission is so arranged that the dots fit between the dashes. A pilot approaching the aerodrome along the safest line of approach therefore hears a continuous note in his headphones, i.e. dots plus dashes, whereas if he is off this path he will receive dots or dashes and will then know which direction to bear in order to obtain the correct path. The pilot need not necessarily rely upon his ears for guidance. There is a visual indicator on his instrument panel, which tells him he has to steer left or right to gain the correct landing path. About two miles out from the aerodrome, and directly on the correct landing line, is another transmitter sending out a vertical wireless beam, with an intermittent signal of a low note. On hearing this the pilot knows he has two more miles to travel and begins to glide in at such a rate that he will only be about 100 ft. up when he crosses the aerodrome boundary. At this height the pilot can usually see the ground and thus make a normal landing. If, however, it is impossible to see the ground the plane can be guided in on a radio

beam which curves up from the aerodrome. An indicator on his instrument panel shows him if he is above or below this beam.

Outline briefly without sketches one " speech on light " system of communication with which you are acquainted and mention the limitations of such a system.

One form of "speech on light" communication consists of a transmitting station and receiving station within visual distance of one another, the transmitting station projecting a beam of light on to the receiving apparatus at the receiving station. The light source at the transmitting station is of constant intensity and the speech waves are caused to modulate the outgoing beam of light. The modulated beam is sharply focussed on to the receiving apparatus which incorporates a photo-electric cell and amplifiers. The photoelectric cell detects the changes in light intensity and converts them to changes in electrical pressure. These electric current variations are fed through amplifiers to the loudspeaker or headphones where they are converted to speech currents. The limitations of any speech on light system are:

(1) The distance over which communication can be effected is limited (generally within visual distance only).

(2) Transmission is seriously affected by adverse weather conditions, such as fog and rain.

(3) All speech on light systems lack secrecy.

(4) For night operation, the transmitter and receiver must be either lined up on the previous day—or else at night by showing a red light at the receiver.

With reference to (2) above, the use of infra-red light as the medium has been found to penetrate fog and rain to a marked degree.
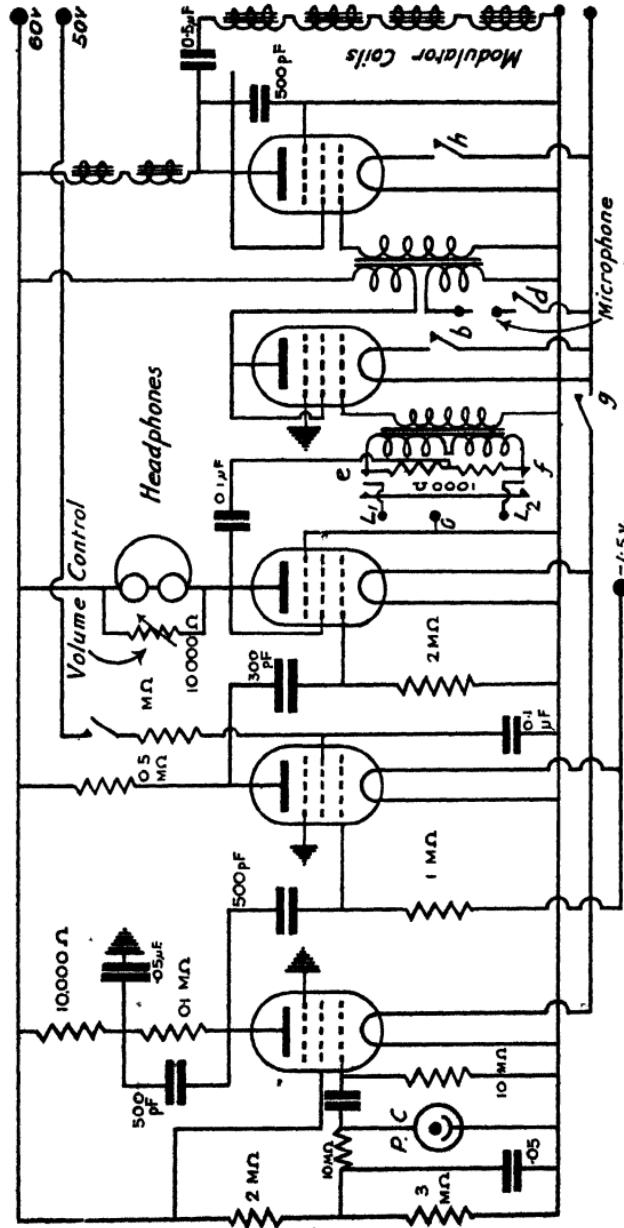
FIG. 145.

(By courtesy of "Electronic Engineering.")

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Draw circuit diagram of a combined transmitter-receiver unit suitable for speech on light.

Fig. 145 shows the required circuit diagram.

Separate amplifiers are used for transmitting and receiving, high gain directly heated pentodes being used. Incoming light variations are converted to changes of electric potential by the photo-cell and these are amplified by the one-stage photo-cell amplifier. The output is then fed to the main receiving amplifier which consists of two valves in cascade; resistance capacity coupled, and the last valve, triode connected to secure a low impedance for the headphones. The transmitting amplifier normally uses but one valve, triode connected. This is fed by the microphone, and the anode is parallel fed by a low frequency choke, the anode load being the armature coils of the modulator. The action of the modulator has been discussed on page 248.

With the circuit shown the change-over from transmitting to receiving is achieved by means of the send-receive switch.

Describe the " speech on light " transmitting apparatus referred to in the previous question, paying special attention to the modulating device.

The transmission system consists of a constant intensity lamp behind which is placed a mirror. This reflects light striking it to the lens L_1, which focusses the light on the modulator unit. The beam of light is partially reflected at two points on the large prism, Fig. 146 and then passes to the transmitting lens which focusses the beam of light on the distant receiving station. The modulator is best understood by reference to Fig. 146. The beam of light after passing through the lens L_1, strikes the hypotenuse side of the large prism. Here, the light beam is reversed by two internal reflections of the prism. The other angles of the prism are not quite 45°, so that at the point of
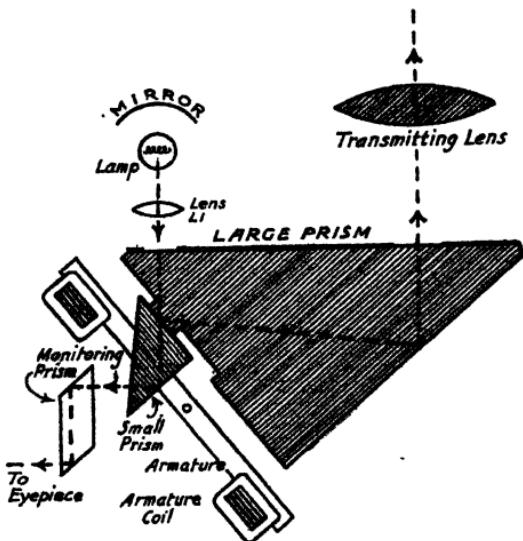
FIG. 146.
(By courtesy of "Electronic Engineering.")

first reflection the mean angle of incidence is approximately the critical angle for glass and air media. Partial reflection and refraction therefore takes place. The area at which this first reflection takes place is a small rectangle the surrounding glass being blackened. The armature consists of a flat metal strip, pivoted at its centre, with the ends located closely between the pole pieces of the armature coils. The action of the coils on the ends of the strip is such that one end is attracted and the other repelled.

Attached to the centre of the armature is a small right-angled prism with one of its sides in contact with the small rectangle of the large prism. The speech currents passing through the armature coils therefore causes the degree pressure to vary between the small moving prism on the armature and the rectangle of the large prism. . This change of pressure between the two surfaces causes an alteration in the degree of reflection at this surface of the transmitted beam of light. Thus the beam of light is caused to vary in intensity in direct relation to incoming speech currents

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flowing in the armature coils, i.e. the light beam is modulated in accordance with speech.

You have decided to start your own business as a Radio Engineer, and a room at the back of the shop is to become your Laboratory for repairs. Assuming that you had adequate finance, list the equipment and fittings that you would instal to carry out the repair work.

Fittings.

(1) The room should first be screened as a protection against radio and other interference.

(2) A strong bench along one wall, preferably in front of windows, to utilise natural light whenever possible.

(3) A portable lighting set associated with the bench.

(4) Electric soldering iron installation.

(5) Suitable filing cabinet for accommodating various receiver data.

(6) High grade interference free aerial and earth system.

(7) Adequate power points complete with multi-adapters.

Equipment.

(1) A sub-standard variable frequency oscillator.

(2) A first grade multi-range universal testing instrument such as universal Avometer or Radio lab.

(3) A Wavemeter or frequency measuring set.

(4) A valve tester such as the universal Avo valve tester.

(5) A Wee megger-tester for high-resistance measurement.

(6) A large stock of various type valves.

(7) A pair of headphones.

(8) A Comparison Receiver.

(9) A Multi-range Valve Voltmeter for use in circumstances when it is inadvisable to use a Universal measuring instrument.

(10) Portable cathode ray oscilloscope; essential for lining up superheterodyne receivers.

CHAPTER XIII

RADIO-COMMUNICATION EXPERIMENTS

KEY TO EXPERIMENTS

Expt. 1. To plot the characteristics of a diode valve.

Apparatus Required.

A valve holder and valve, a high-tension battery, a potentiometer, a voltmeter to determine the high-tension voltage, a milliammeter to measure the anode current, and a filament battery, ammeter and variable resistance.

Procedure to Adopt.

The apparatus should be connected as shown in Fig. 147. Adjust the filament resistance Rf and obtain the correct filament current; record this in Table 1. Next

FIG. 147.

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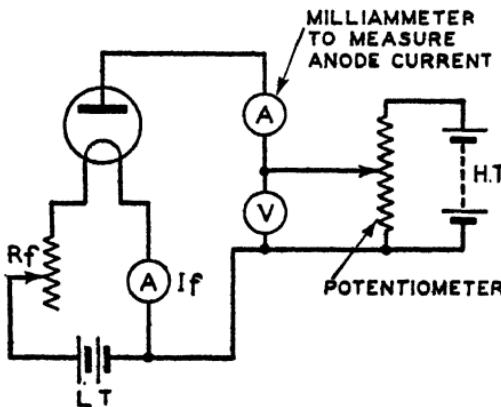
note the current flowing in the ammeter, with a fairly low anode H.T. voltage applied, record these in Table 1. Keeping the filament current constant, raise the high-tension voltage H.T. in definite steps, noting these together with the corresponding anode current readings in Table 1. From the table of results plot a graph

TABLE 1.

Filament Current	Anode Voltage	Anode Current

and if the valve is satisfactory it should have the form of the curve shown in Fig. 148. Repeat the above procedure using different filament currents. The shape of the curve should remain the same but saturation point should be reached at a lower value.
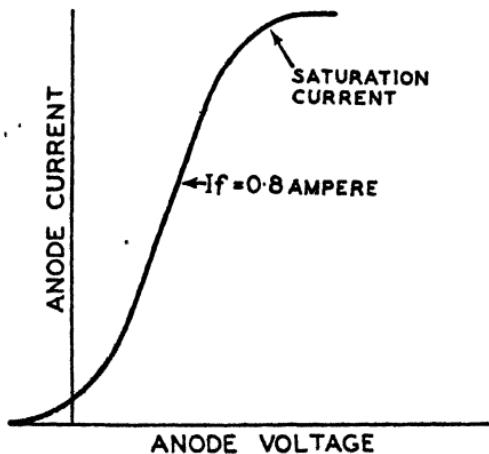
FIG. 148.

NOTE.—The voltmeter must be connected to the battery side of the milliammeter, so that the latter is not affected by the voltmeter current. Fig. 149 shows in
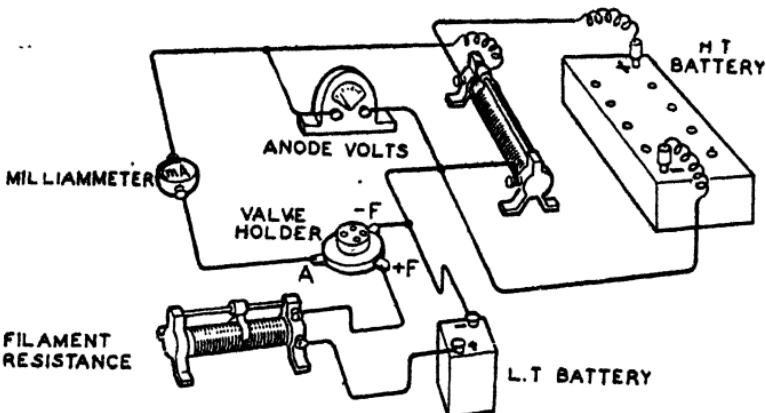
FIG. 149.

practice the actual wiring arrangement, and should
help students who are setting up a circuit of this nature
for the first time. This type of arrangement will not,
however, be illustrated in subsequent experiments.

**Expt. 2. To plot the mutual characteristics of a
triode valve.**

Apparatus Required.

A grid bias battery and grid potentiometer, a volt-
meter to measure the grid voltage Vg, a filament battery
consisting of secondary cells, a filament rheostat, a
high-tension battery H.T., together with an associated
potentiometer, a voltmeter to measure the anode
potential and a first grade milliammeter to measure the
anode current flow, also a valve holder and suitable
valve.

Procedure to Adopt.

The apparatus should be connected as shown in
Fig. 150. The H.T. voltage should be adjusted to the
stated H.T. working voltage of the valve. The grid
bias potentiometer is adjusted so that a negative
potential of three volts is applied to the grid electrode
of the valve, and the correct voltage applied to the
filament terminals. The anode current as indicated by

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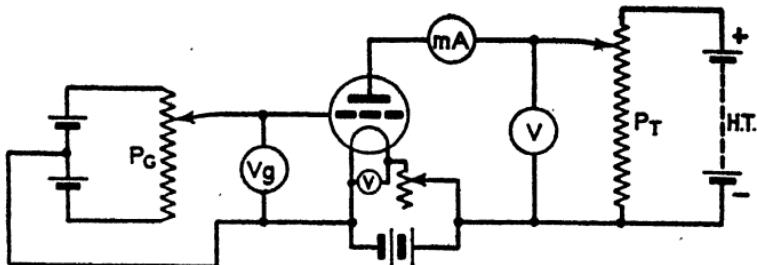
the milliammeter should be recorded in Table 2, together with grid and anode voltages. This completed, the grid bias potentiometer should be adjusted so that the potential on the grid (as read by Vg) is increased by one volt, i.e. from —3 volt to —2 volt. The H.T. voltage is maintained constant and the new current flowing as shown by the milliammeter.

The grid bias voltage should again be increased one volt, this time to —1 volt and the current flowing in the milliammeter recorded. This procedure should be

TABLE 2.

FILAMENT VOLTS = 2

ANODE VOLTAGE	GRID BIAS VOLTAGE	ANODE CURRENT
100 Volts	-3	0·37 m As
"	-2	0·52 "
"	- -1	1·5 "
"	0	2·3 "
"	1	4·0 "
"	2	5·5 "
"	3	7·1 "
"	4	8·7 "

repeated with zero potential, then + 1, + 2, + 3, + 4 volts, etc., applied to the grid electrode. The type of mutual characteristic curve obtained should be similar in shape to that shown in Fig. 151. The graph should be
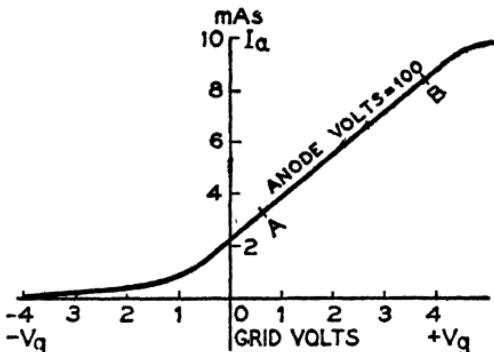
FIG. 151.

drawn with grid voltage as the abscissa and anode cur-rent as the ordinate. The mutual conductance of the valve is then obtained from the slope of the curve.

Mutual conductance $= \dfrac{\text{Change in anode current}}{\text{Change in 1 volt of grid bias}}$

This reading should be taken at the straight line part of the curve, i.e. between points A and B in Fig. 151

With $Vg = 2$ volts $+ Ia = 5 \cdot 5$ ma.

With $Vg = 1$ volt $+ Ia = 4 \cdot 0$,,

Difference of 1 volt gives $1 \cdot 5$ ma. difference in anode current.

Mutual conductance $= 1 \cdot 5$ milliamperes per volt (mA/v).

Conclusions.

The anode current is small when the grid voltage is negative and high when the grid voltage is positive. Small positive changes of grid voltage produce corresponding large variations in anode current.

Expt. 3. To determine the anode voltage/anode current characteristic of a three-electrode valve.

Apparatus Required.

The same apparatus as required for Experiment 2.

Procedure to Adopt.

The apparatus should be arranged as shown in Fig. 150.

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The grid potentiometer should be adjusted to produce a desired grid voltage and this should then remain constant for the remainder of the test. With the H.T. potentiometer adjusted so that the anode voltage is

TABLE 3.

Anode Current	Anode Voltage	Grid Voltage
0	0	Constant
3 5 mA	5υ	0
8 0 "	15	"
.4 0 "	100	"

small, say 30 volts, the current flowing in the milliammeter is recorded in Table 3 as shown. The anode voltage should then be increased to 40 volts, and then 50, and 60 volts, etc., by the adjustment of *PT* and at each stage the anode current should ne noted in Table 3. A curve with anode voltage as the abscissa and anode current as the ordinate should then be plotted, and a curve obtained similar to Fig. 152 if the valve is satisfactory.

Comparing this experiment with No. 2 it will be seen that in Experiment 2 small changes of grid voltage
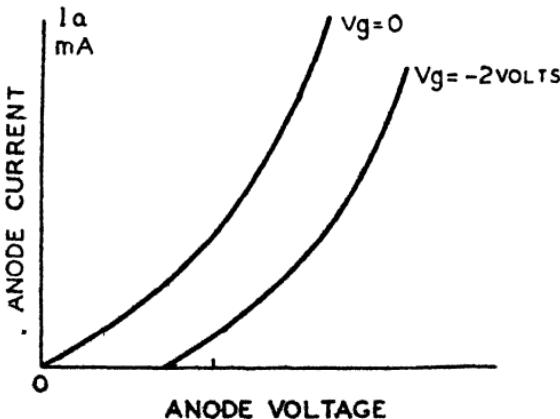
Fig. 152.

cause large changes in anode current, but to produce equal changes of anode current in this experiment the change of anode current voltage is considerable. It will be noticed that the curve tends to flatten out as ·the voltage rises, this indicates an approach to the maximum electron current which the filament can emit. The experiment should then be repeated using a differ-,ent grid voltage, say — 2 volts.

Conclusions.

With a high negative grid voltage, it will be found that the anode voltage must be considerably higher to obtain the same value of anode current compared with a curve using a slightly lower negative grid voltage.

.·Expt. 4. To determine the anode voltage/anode current characteristic of a screened grid valve.

The screened grid valve has an additional grid electrode as shown in Fig. 153, the grid nearest the anode plate is known as the screen grid and the lower grid the control grid. The effect of the screen grid on the anode voltage/anode current characteristic will be plain when comparing the curve in Fig. 155 with the curve in Fig. 152, Experiment 3.

Apparatus Required.

Four voltmeters, a grid potentiometer and a filament resistance, a high-tension battery and a low-tension battery, a filament ammeter, a milliammeter to measure the anode current, a valve holder and suitable valve.

Procedure to Adopt.

The apparatus should be connected as shown in Fig. 154. The screen lead should be plugged in the high-tension battery at about 80 volts say, and kept constant, the filament voltage and current should be adjusted to the desired value by the filament resistance. Make the grid potential + 1 volt by adjusting the grid potentiometer. Next vary the anode voltage in steps of 6 volts up to + 20 volts, and with each fresh anode

FIG. 153.

TABLE 4.

GRID VOLTAGE	SCREEN GRID VOLTAGE	ANODE VOLTAGE	ANODE CURRENT mA

ANODE PLATE
SCREEN GRID
CONTROL GRID
FILAMENT

voltage reading, check the anode current flowing in the milliammeter. Record the readings in Table 4.
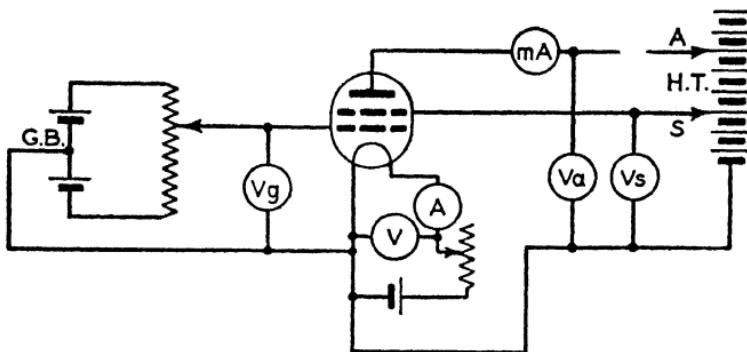
FIG. 154.

Using the results obtained plot a graph using anode voltage as the abscissa and anode current as the ordinate; the curve should appear similar in shape to that shown in Fig. 155 if the valve is satisfactory.

Repeat the experiment using different control grid voltages and also different screen grid voltages.

The Reason for the Introduction of the Screen Grid.

When triode valves are used in radio-frequency amplifying stages the amplifier is liable to burst into self oscillation due to retro-action through stray capacitances between anode and grid circuits and in particular through the capacitance existing between the anode and grid themselves. This effect is eliminated by interposing a screen or further grid between the

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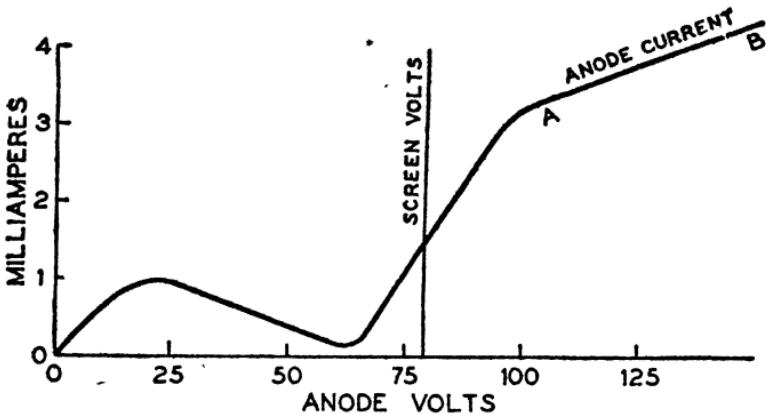
FIG. 155.

anode and the control grid and applying a fixed D.C. potential to it. The function of the screen grid, therefore, is to eliminate the grid anode capacitance of the valve.

Conclusions.

At first the electrons are attracted to the screen grid and remain there, none flowing on to the anode because of its low potential. As the anode potential is increased, however, a few electrons commence to reach the anode causing a current to flow. It will be seen from Fig. 155 that at this stage the current commences to rise steeply with each increase in anode voltage. As the anode potential is increased still further, the electrons hitting the anode will cause secondary emission, i.e. will release further electrons which, since the screen grid is positive to the anode, will be attracted back to the screen. The anode current will, therefore, decrease once more until the anode potential becomes almost equal to that on the screen. When the anode potential exceeds the screen potential electrons emitted from the anode due to secondary emission will not be attracted to the screen, but will return to the anode. Thus the current will rise once more.

NOTE.—The working part of the characteristic is that between the points *A* and *B*.

Expt. 5. ***To determine the screen current/anode voltage curve of a screen grid valve.*** ***Comparison of screen current with anode current for the same change in anode volts.***

Apparatus Required.

The same apparatus as Experiment 4.

Procedure to Adopt.

Connect the apparatus as shown in Fig. 154, with the exception of the milliammeter which should be taken from the anode lead and connected into the screen lead to the H.T. battery. As in the previous experiment the grid bias should be adjusted to give + 1 volt, with screen volts 80, and zero anode volts.

Note the current flowing in the milliammeter connected in the screen lead and record this in Table 5. Proceed as in Experiment 4 to vary the anode voltage

TABLE 5.

ANODE VOLTAGE	SCREEN CURRENT	SCREEN VOLTAGE

in definite stages from zero to 120 volts, and read the screen current at each stage. These values should be recorded in Table 5 and a graph drawn with anode voltage as the abscissa and screen current as the ordinate. This curve should appear similar to that shown in Fig. 156. Now reconstruct on the same graph the anode current/anode voltage curve as shown in Fig. 155 and compare the two curves.

Conclusions.

The two curves have exactly opposite shapes. When the anode current is a maximum the screen current is a minimum, and when the screen current is a maximum the anode current is a minimum. One rises,
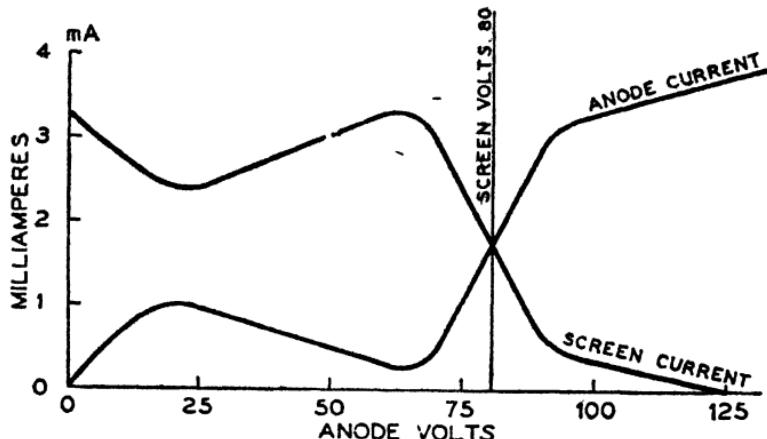
FIG. 156.

the other falls at the commencement, then at roughly
17 volts the rising anode current turns and commences
to drop, whereas the falling screen current turns and
commences to rise again. This is due to secondary
emission. As the anode voltage nears the fixed screen
voltage the anode current curve again turns and com-
mences to rise whereas the curve of the screen current
turns and drops. Both curves cut the 80-volt line at
approximately the same point, i.e. 1·7 milliamperes.

The screen current continues to fall and the anode
current to rise. Let us study the screen current/anode
voltage curve separately. It will be seen that when
the anode voltage is zero the screen current is a maxi-
mum. This is because there is no electron flow
between the screen and the anode plate, so that all the
electrons emitted from the filament via the grid are
collected on the screen electrode. As the anode
potential increases, however, some of the electrons are
attracted to the anode electrode to the detriment of
the screen current, with the result that the screen
current commences to drop. Subsequent increases in
anode potential cause a fairly rapid reduction in the
screen current, and the commencement of a rapid

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flow of electrons through the screen to the anode plate. This flow becomes too rapid at a point where the anode voltage is about 17 volts, with the result that a large proportion of the emitted electrons fall from the anode plate and are attracted back to the screen which is at a higher potential. The screen current consequently commences to rise again, and continues to do so until the anode potential reaches about 60 volts. At this point the curve again turns; the screen current commencing to fall. With each subsequent increase of anode voltage the screen current drops towards zero.

Expt. 6. To determine the characteristic of a diode valve with various load resistances.

The dynamic characteristic curves are by far the most important as they give a true picture of the valve under working conditions. If you look at any wireless valve circuit you will see that inserted in the lead from the anode electrode to the H.T. battery is a resistance, usually of several thousand ohms. This resistance is called the anode load resistance or impedance. In Figs. 150 and 154 this resistance was omitted and the curves obtained therefore do not represent the true working curves of the valve. They are called Static curves.

Apparatus Required.

A high-tension and low-tension battery, a potentiometer, a filament ammeter, an anode milliammeter, two voltmeters, a valve holder and valve, a filament resistance, connecting wire, a variable high resistance and a short-circuiting key.

Experimental Procedure.

The apparatus should be connected as shown in Fig. 157, and an anode current/anode voltage static curve obtained with the anode load resistance R short-circuited by closing the key K. The anode voltage and current values should be recorded in Table 6A and a curve plotted. The key should then be released and the anode load resistance adjusted to 5,000 Ω. A
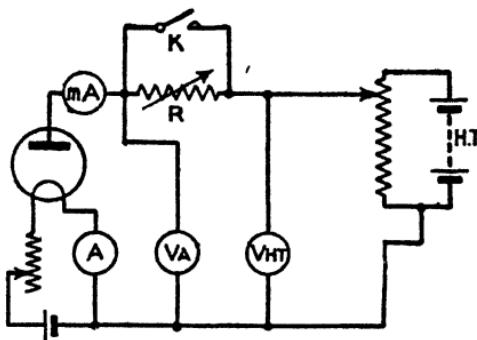
FIG. 157.

second series of anode voltage/anode current values should be tabulated—Table 6B—and from the results obtained a curve B plotted. The anode load resistance should then be altered to ten thousand ohms and a third series of anode current values obtained, Table 6c. From the figures obtained draw a third curve (C), Fig. 158.

Conclusions.

It will be noticed that the slope of the anode current curve decreases as the anode load resistance increases. The curves can be checked in the following manner. Looking at Fig. 157, it will be seen that with the key K short circuiting the anode load resistance R, the anode

TABLE 6A.		TABLE 6B.		TABLE 6c.	
ANODE VOLTAGE	ANODE CURRENT	ANODE VOLTAGE	ANODE CURRENT	ANODE VOLTAGE	ANODE CURRENT
0	0 mA	0	0 mA	0	0 mA
20	1 "	20	0 75	20	0·55
40	3 7 "	40	2	40	1·5
.60	5·0 "	60	3 6	60	2·5%
80	5 25 "	80	4 65	80	3 6
100	5 28 "	100	5·2	100	4·6

(a) STATIC FIGURES   (b) ANODE LOAD 5,000Ω   (c) ANODE LOAD 10,000Ω

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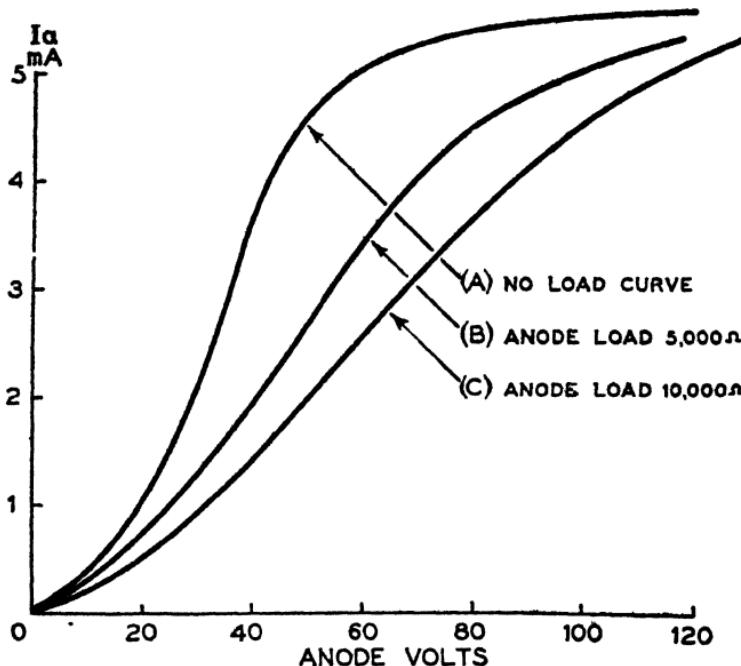
FIG. 158.

voltage Va will be equal to the high-tension voltage V_{HT}, but when K is released there will be a voltage drop across the resistance R equal to IR. Where I is the anode current flowing and R is the value of the anode load resistance. Take a point x on the curve A, Fig. 158, such that the current at this point is 1 milliampere and the anode voltage 20, if a load resistance 5,000 ohms is inserted in the circuit there will be a

voltage drop across this resistance, equal to $\dfrac{1}{1000} \times$

5,000 = 5 volts. Thus the voltage at the anode plate will drop to 20–5 = 15 volts. If, therefore, we wish to maintain an anode current flow of 1 mA., the H.T. voltage must be increased 5 volts, i.e. from 20 to 25 volts. For confirmation look at curve B where the

anode voltage is 25 volts and you will see that the anode current is 1 mA.

Expt. 7. To plot the dynamic characteristic of a triode valve and obtain its amplification.

Consider a circuit where a triode valve has a resistance in series with its anode. This produces a drop in anode volts proportional to the anode current in a similar way to the diode case explained in Experiment 6. The relation between the change in grid voltage and the change in anode current is then no longer the static characteristic for constant anode volts as shown in Experiment 2, but will be a line of less slope cutting across the static curves.

Apparatus Required.

A triode valve and valve holder, a grid bias battery and potentiometer, a high-tension battery and potentiometer, an anode current milliammeter, three voltmeters for the grid, H.T. and anode voltages, a variable known high resistance and a short-circuiting key.
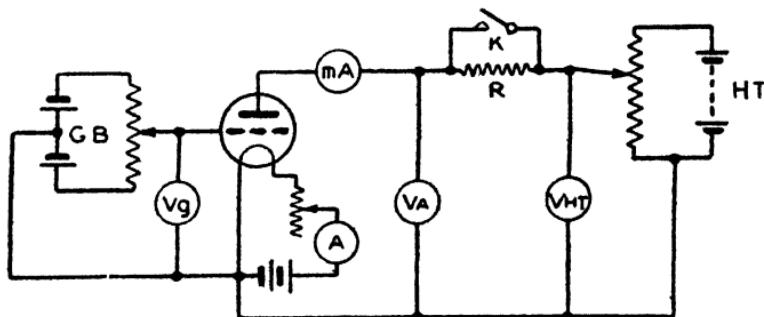
FIG. 159.

Experimental Procedure.

The apparatus should be connected as shown in Fig. 159, and a family of mutual characteristic curves, Fig. 160, plotted as shown in Experiment 2. For this part of the experiment the key K should short circuit the anode load resistance R. This completed, adjust the

anode voltage to 130 volts, make R equal to 20,000 ohms and adjust the negative grid bias until no current flows in the milliammeter. When the grid bias is sufficiently negative to prevent the flow of anode current, the potential of the anode with respect to the filament or cathode will be the same as that of the H.T. battery which is 130 volts (since there is no IR drop) and the conditions will be represented on the family of mutual characteristics by the point (A). Next adjust the grid bias voltage until a current of 0·5 mA. flows in the milliammeter. The voltage drop across the
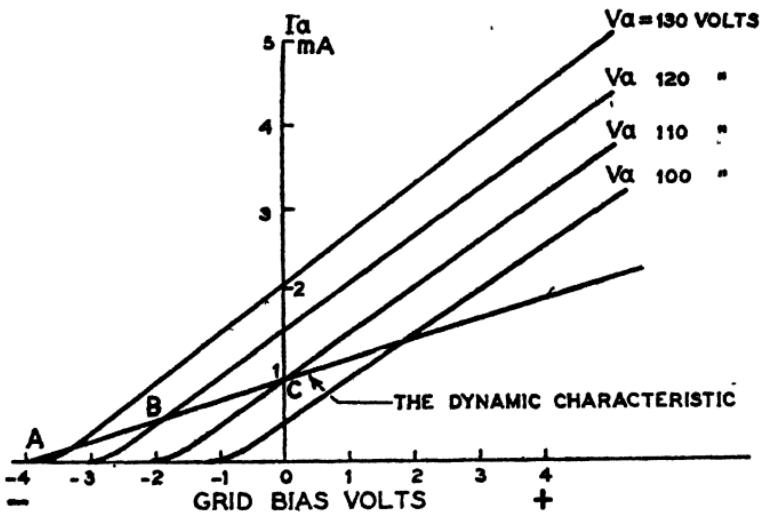
FIG. 160.

anode load resistance R equals $\dfrac{0\cdot5}{1000} \times 20{,}000 = 10$ volts, and the new conditions will be represented by the point (B) on the 120-volt characteristic where $Ia = 0\cdot5$ mA., and $Vg = 1\cdot9$ volts. Now adjust the grid bias so that the anode current flowing is 1·0 mA. The voltage drop across the load will then be 20 volts (20,000 × 0·001) and the new conditions are represented by a point (C) on the 110 volt characteristic

TABLE 7.

GRID BIAS	FIXED ANODE VOLTS			
	130 VOLTS	120 VOLTS	110 VOLTS	100 VOLTS
−4 Volts	Ia 0 mA	Ia 0 mA	Ia 0 mA	Ia
−3 "	0·5 ·	0·	0 ·	—
−2 ·	1·0 ·	0·5·	0 ·	—
−1 ·	1·5 ·	1·0·.	0·5·	0
0 ·	2·0 ·	1·5·	1·0 ·	0·5
1 ·	2·5 ·	2·0·	1·5·	1·0
2 ·	3·0 ·	2·5·	2·0·	1·5
3 ·		3·0·	2·5·	2·0

with the grid bias at zero potential. The line joining the succession of points ABC is known as the *dynamic characteristic* corresponding to the external load of 20,000 ohms. It is nearly straight except for a small portion at the extreme end near (A). The experiment should be repeated using various anode load resistances, and various dynamic characteristics obtained.

Conclusions.

As the value of the anode load resistance is increased the anode voltage Va will decrease and hence the slope of the dynamic characteristic will become less. After a careful study of Fig. 160 the student will observe that to produce an anode current change of, say 0·5 mA., a change of grid potential of 1·9 volts is necessary, e.g. from zero to − 1·9. This will produce a voltage variation of 10 volts across R. The point to remember (about this function) is that when a resistance is connected in the anode circuit, the *change* in anode current causes a variation in voltage across this anode load resistance which will be a magnified version of the change in grid voltage. In other words there is amplification and the valve acts as an amplifier.

Expt. 8. To obtain the A.C. resistance or impedance of a wireless valve.

Apparatus Required.

The same apparatus is required for this experiment as in Experiment 7.

Experimental Procedure.

With the apparatus connected as shown in Fig. 159 a family of mutual characteristic curves should be plotted similar to those in Fig. 160. Then the A.C. resistance of a valve represents the resistance expressed in ohms which the anode circuit offers to a small increase of anode voltage. From Fig. 160 curves *A*, *B* and *C* represent such changes, with an anode potential of 130 volts and zero grid potential, the anode current equals 2 mA., when, however, the anode voltage is reduced to 120 volts with the same grid condition, zero, the anode current will be 1·5 mA.

Therefore, *the ratio of the change in anode volts* to the *change* in anode current in *amperes* gives the A.C. resistance of a valve. Thus:

$$\text{A.C. resistance } (ra) = \frac{\text{Change in anode volts}}{\text{Change in anode current}}$$

$$\text{or } r_a = \frac{\delta Va}{\delta Ia}$$

Inserting our values $\dfrac{130 - 120}{\dfrac{2 - 1·5}{1000}} = \dfrac{10,000}{0·5} = 20,000$

Thus the A.C. resistance of the valve is 20,000 ohms.

Conclusions.

The student will no doubt notice the similarity between the above formula and the D.C. resistance formula:

$$R = \frac{V}{I}$$

This should provide an easy method of remembering the correct formula. They are not the same, however, and it is to be noted that *changes* of anode current and

voltage are referred to, *not* actual values of voltage and current.

THE AVODAPTOR

It may be necessary in practice to test a valve under normal working conditions, i.e. in the radio set or amplifier, etc., of which it forms a part. Tests, then, are not quite so easy as those outlined in Experiments 1 to 8, especially from an accessibility point of view. For tests under normal working conditions an "Avodaptor" should be used; this instrument overcomes inaccessibility.

The instrument consists of a valve-holder, the connections to the sockets of which may be interrupted by a rotary switch, thus allowing a current meter to be inserted in certain feeds without alteration to the exterior wiring. The switch has seven clearly defined positions, each of which is made positive by the ratchet action of the contacts. To this testing holder is attached a flexible cable, the other end of which terminates in a plug, and, as the terminals on the testing base are directly connected to the pins of this plug, voltages applied to the various electrodes of the valve under test may be measured without interfering with the wiring of the radio receiver, etc., in any way. The plug of the instrument is convertible for either 4- or 5-pin valves, and two small contact studs on the side of the plug are connected via terminals on the testing base to an Avocoupler which facilitates the testing of 7- or 9-pin valves. This instrument is made by the Automatic Coil Winder & Electrical Equipment Co., Ltd., London.

A few words before we pass on to the more intricate experiments. As you no doubt know the wireless signals received are of an oscillatory nature and this alternating potential is applied to the grid which has a fixed grid bias potential on it. The result is that the grid voltage is varied; for example, if the grid has a fixed negative bias of − 3 volts, and an oscillatory potential of 1 volt is applied to it, then at one stage the resultant grid voltage will be − 3 + 1 = − 2 volts,

and at the next instant the voltage will be $-3 - 1 =$ -4 volts. Thus the grid voltage will vary between -4 and -2 volts.

Voltage Amplification Factor (V.A.F.).

The degree of amplification which the valve is capable of (as was shown in Experiment 7) is known as μ (*mu*) the amplification factor, and is an important valve constant. A change of grid voltage brought about by an alternating potential applied between the grid and cathode produces an amplified voltage variation across the load resistance R. It should be noted that this variation also takes place across the A.C. resistance r_a of the valve.

The voltage across the anode load resistance R will be proportional to the ratio of R to the total anode resistance which is $r_a + R$, i.e. the ratio $= \dfrac{R}{r_a + R}$

Then if Vg and V_R represent the input and output voltages respectively,

V_R the voltage across $R = \mu Vg \times \dfrac{R}{r_a + R}$

$$V_R = \frac{\mu VgR}{r_a + R} \qquad\qquad (1)$$

The Voltage Amplification Factor (V.A.F.) is the ratio of output voltage to the input voltage.

$$\text{V.A.F.} = \frac{\text{Output Voltage}}{\text{Input Voltage}}$$

Hence $\text{V.A.F.} = \dfrac{\mu VgR}{r_a + R} \div Vg$

$\therefore \text{V.A.F.} = \dfrac{\mu R}{r_a + R}$

It will be seen, therefore, that when the voltage of the grid swing is high, that is positive, the anode current will be high also; thus the anode voltage will be low. Conversely when the voltage of the alternating potential or grid swing is low, that is negative, the anode current will be low and the anode voltage high.

Expt. 9. To plot the "load line" of a triode valve.

The voltage developed across the anode load resistance has been shown to be the important factor of a voltage amplifier, and its value can be easily found with the assistance of a line drawn through a family of anode voltage/anode current curves. The line represents the anode load resistance and its value is determined by its slope.

Apparatus Required.

High-tension, low-tension and grid bias batteries, a valve holder and a triode valve, voltmeters, an ammeter, a milliammeter, a potentiometer for varying the grid bias potential, a filament resistance, connecting wire, a potentiometer for H.T. variation, an anode load resistance and short circuiting key.

Experimental Procedure.

The apparatus should be connected as shown in Fig. 161, and a family of anode volts anode-current curves plotted, i.e. with varying grid bias voltages; say from $Vg = 0$ to $Vg = -6$ volts. See Fig. 162. For this test the key K should short-circuit the anode load resistance R. The key should be released and the value of R ascertained, say 20,000 ohms.

It was shown that depending on the value of the anode current there is a voltage drop across this
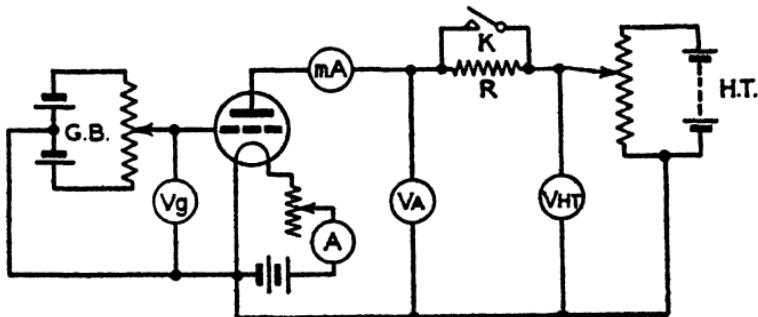
FIG. 161.

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resistance equal to IR. Thus the voltage at the anode plate is the H.T. voltage less the IR drop. The H.T. voltage should be adjusted to a hundred volts and the grid bias volts so negatively biased that no anode current flows. With these conditions the anode a point A in Fig. 162. The value of anode current voltage is the same as the H.T. voltage, and shown by giving the maximum voltage drop across the anode load resistance should next be ascertained; this will be when the anode plate voltage is zero and the H.T.
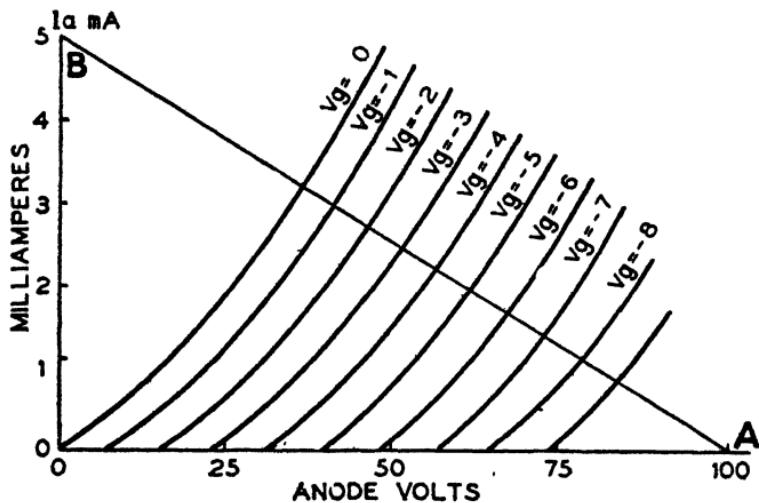
FIG. 162.

·voltage is 100. Under these conditions $IR = 100$.

$I = \dfrac{100}{20,000}$ amperes or 5mA. (point B, Fig. 162).

Draw a straight line AB cutting the family of anode voltage/anode current curves.

AB is known as the load line.

Repeat the experiment using different values of anode load resistance.

Conclusions.

The load line is a line drawn on a graph of the anode volts/anode current characteristics and is the locus of

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a point representing the anode voltage for different values of anode current. This load line passes through the point whose co-ordinates are zero anode current and the full anode supply voltage, and makes an angle with the axis whose tangent is equal to the anode load resistance. Being of a straight line form the slope of the load line can be ascertained from two points through which the line passes, and connecting them with a straight line.

The slope of the anode load line varies according to the value of the anode load resistance.

Expt. 10. To determine the characteristic curve of a copper oxide rectifier.

The metal rectifier, no matter of what material construction, must possess one fundamental characteristic, that is, to offer a high impedance when the applied P.D. is in one direction and a low impedance when the applied P.D. is in the opposite direction. Thus the rectifier permits a large current to flow when the applied P.D. is in one direction and little or no current when this applied P.D. is reversed. Fig. 163 show show the impedance of the rectifier varies with the applied P.D.

The ratio $\dfrac{\text{Forward Impedance}}{\text{Backward Impedance}}$ is a constant for any
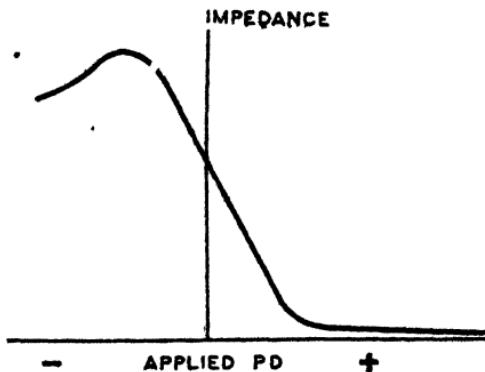
FIG. 163.

one form of rectifier. The graphical way of showing a rectifier is shown in Fig. 164. The arrow head is the negative element and the bar the positive element.

Apparatus Required.

A battery, a potentiometer, a voltmeter, a micro-ammeter, a milliammeter, a copper oxide rectifier and connecting wire.

Experimental Procedure.

The apparatus should be connected as shown in Fig. 165, and a series of voltage and current readings taken between say + 4 volts and − 4 volts. When the potentiometer slide is moved from the positive to the negative side the milliammeter should be replaced by
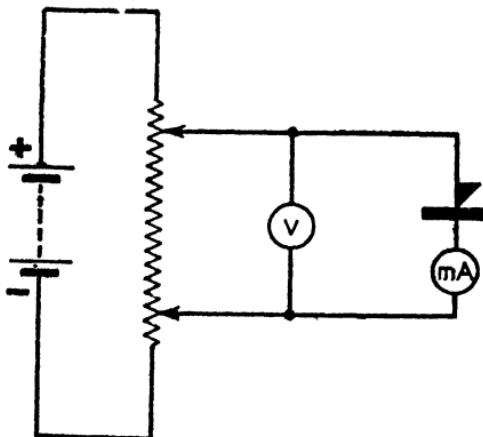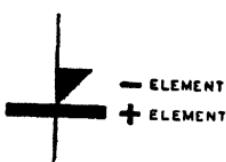
FIG. 164.

FIG. 165.

the microammeter, as the current flow is extremely small, the impedance of the rectifier being high. These voltage and current readings should be recorded and a graph plotted with voltage as the abscissa and current as the ordinate. Fig. 166 shows the shape of the curve.

Conclusions.

The apparatus acts as a means of rectifying an alternating current; it offers high impedance to nega-tive potentials and thus only permits a small current
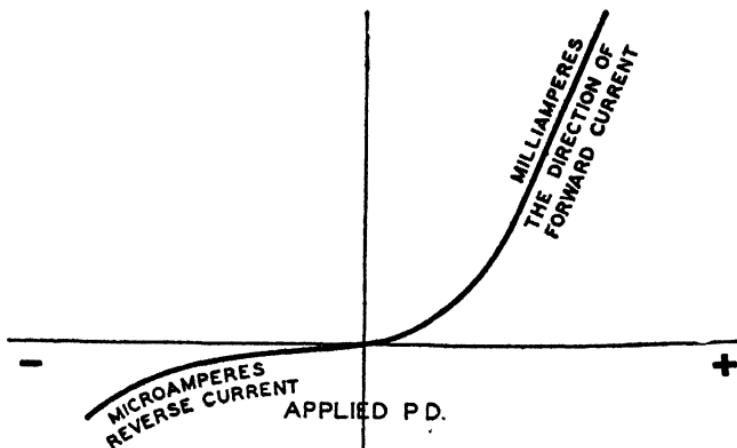
Fig. 166.

to flow, but permits a large current to flow with a positively applied potential.

Expt. 11. To check the characteristics of a voltage stabilising valve.

The voltage stabilising valve as its name suggests is a specially constructed valve whose function is to keep the voltage of the circuit with which it is associated constant, independent of the value of the current flow. The test applied to check the valve consists of varying the load current and ascertaining that no voltage variation occurs.

Apparatus Required.

A high voltage supply (240 volts), a potentiometer, two voltmeters, two milliammeters, a load resistance, a valve holder and a voltage stabilising valve.

Experimental Procedure.

The apparatus should be connected as shown in Fig. 167, and the anode voltage adjusted to say, 190 volts. The load resistance should then be reduced until the valve operates (or strikes). The voltage reading of V_s should be noted in Table 8.

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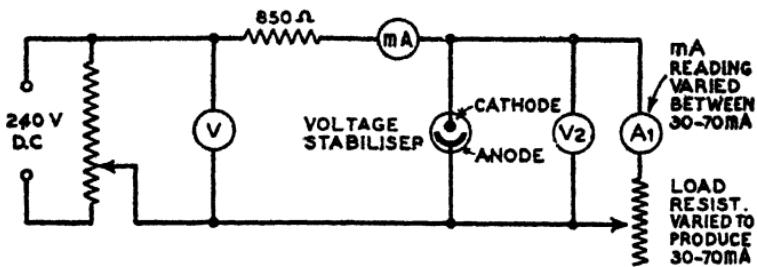
FIG. 167.

TABLE 8

VOLTAGE READING V₂	CURRENT FLOWING mA
190 Volts	30 mA
189 "	40 "
188·8 "	50 "
188·6 "	60 "
188·4 "	65 "
Cut-off	70 "

The current flowing should then be controlled by adjustment of the load resistance in steps, from 30 milliamperes to 70 milliamperes, and at each stage the circuit voltage V_2 should be noted. This voltage should not vary above ± 2 volts. Plot a graph showing
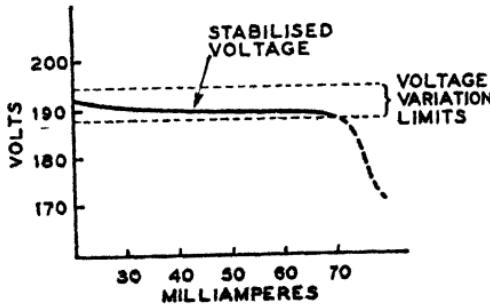
FIG. 168.

this variation of voltage with current as shown in Fig. 168.

***Expt. 12. To determine the characteristics of a
thermal delay switch valve.***

In many types of radio valve, especially some types
of rectifier valves, it is necessary to apply the filament
current for some seconds before applying the anode
voltage. Thus a circuit had to be designed so that
connection of the power supply to the apparatus only
energised the filaments of the rectifiers, application of
the high tension voltage to the anodes being .delayed
until the filaments were satisfactorily emitting. This
condition was achieved by means of the thermal delay
switch. The filament of this valve is wired in series with
the filaments of the other valves in the circuit. This
valve is so designed that when the temperature inside it
increases beyond a certain value, contact is made be-
tween the anode and grid of the valve by means of two
metal strips expanding due to the heat. This contact is
arranged to complete the circuit for the anode voltage
to all the valves of the circuit.

Two tests are applied to determine the characteristics
of a thermal delay switch. The first is the time taken
for the valve to strike when the correct filament
voltage and current are applied, while the second is an
emission test.

Apparatus Required.

A valve holder, a thermal delay switch, an ohm-
meter (or universal instrument with switch to ohms),
a filament voltage supply, two ammeters, a stop-
watch and a high-tension supply.

Procedure to Adopt.

For the time test the apparatus should be connected
as shown in Fig. 169 and the filament current and voltage
adjusted to that specified for the valve. The valve
should then be removed or switched off to permit its
filament to cool. When the filament is cold the valve
is replaced and the time taken for the anode of the
valve to make contact with the grid noted. The
valve is considered to be satisfactory if contact is
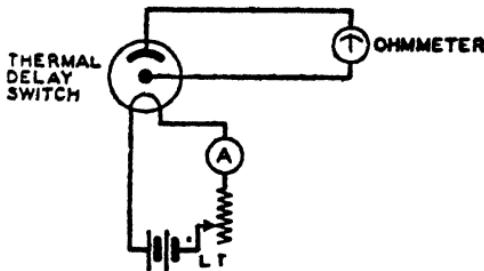
FIG. 169.

established within 20 and 90 seconds after switching on. When contact is established the ohmmeter will register a full-scale deflection (zero ohms).

For the emission test the apparatus should be connected as shown in Fig. 170 with the anode plate disconnected. The emission current flowing should not
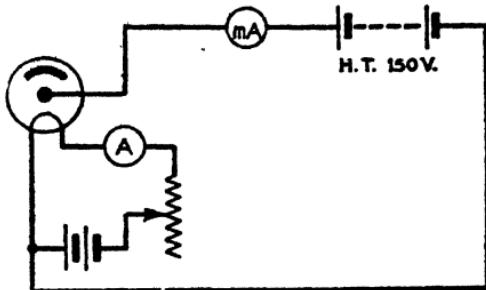
FIG. 170.

exceed 15 mA., at 150 volts H.T. Care should be exercised in adjusting the filament current to the correct value as this is critical.

Expt. 13. To determine the characteristics of a barreter.

In a similar way to the manner in which the voltage stabiliser functioned in keeping the voltage of the circuit constant, so the barreter performs the parallel function of keeping the current flow constant within limits of applied voltage variation.

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Apparatus Required.

A voltage supply, a milliammeter, a barreter and holder, a voltmeter, a potentiometer and connecting wire.

Procedure to Adopt.

The apparatus should be connected as shown in Fig. 171, and the voltage applied to the circuit varied
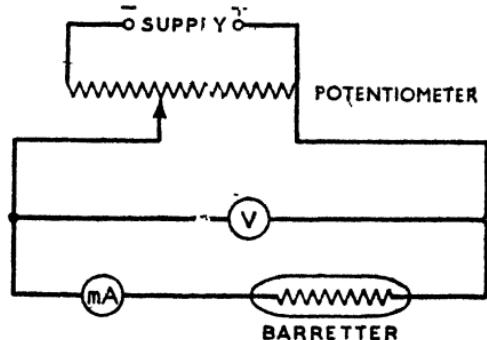
FIG. 171.

in definite steps by the adjustment of the potentiometer. With each voltage adjustment the current should be noted in Table 9, and a graph plotted with
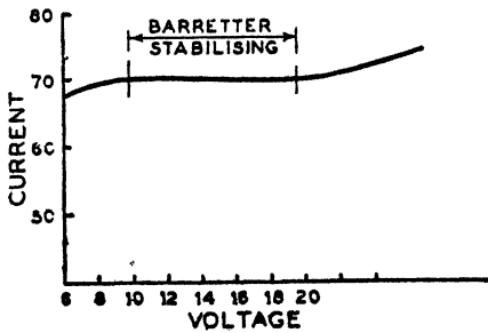
FIG. 172.

volts as the abscissa and current as the ordinate. Once the barreter has stabilised, the current should remain constant within limits.

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TABLE 9

APPLIED VOLTAGE	CURRENT mAS
8	67 mA
10	69·2 "
12	70 "
14	70 "
16	70·2 "
18	70·8 "
20	72·5 "

Expt. 14. To ascertain the voltage ratio or ratio of transformation of a transformer.

By far the simplest method of ascertaining the voltage ratio of a mains transformer is to connect the known primary side to the mains supply and then measure the secondary voltage with an A.C. voltmeter as shown in Fig. 173.
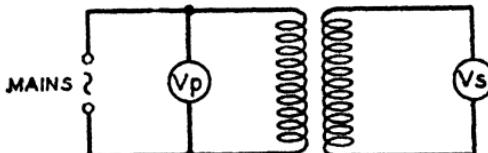
FIG. 173.

The voltage ratio is given by: $\dfrac{Vs}{Vp}$

where Vs is the secondary voltage.

Vp is the primary voltage.

A more accurate method, however, is by means of a resistance ratiometer, as shown in Fig. 174.

Apparatus Required.

An A.C. supply, the transformer to be tested, a pair of headphones and a resistance ratiometer.

Procedure to Adopt.

The apparatus should be connected as shown in Fig. 174. One end of the primary winding should be
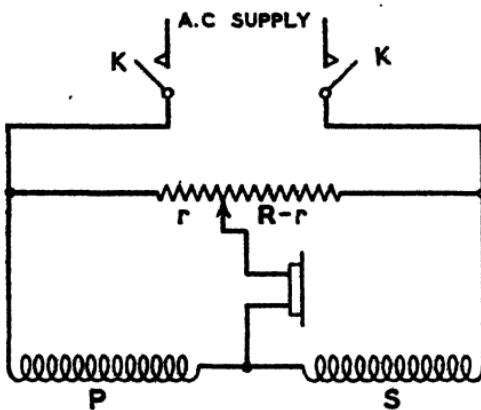
A.C SUPPLY

FIG. 174.

connected to one end of the secondary winding and
to one lead of the headphones. Connect the other side
of the headphones to the sliding contact of the resist-
ance ratiometer. The oscillatory supply should be
connected to the extreme ends of the ratiometer and
then to the free ends of the primary and secondary
windings of the transformer. The key K should then
be depressed and the slider of the ratiometer adjusted
until silence is obtained in the headphones. The

voltage ratio is equal to $\dfrac{R - r}{r}$

The resistance R is usually 1,000 ohms. If, therefore,
a balance were obtained with $r = 200$, the voltage ratio

would be $\dfrac{1000 - 200}{200} = \dfrac{4}{1}$

The transformer has a step-up ratio of 4 to 1.

Conclusions.

The method outlined is known as the *"no-load"*
method, i.e. no load has been given to the secondary side
of the transformer. It will be found in practice that
when a load is applied the secondary voltage of the
transformer does drop due to certain losses, such as
iron and copper losses, etc.

In the first test mentioned the error will probably

be greater if the ratio is high, in which case two different range voltmeters will be necessary.

Expt. 15. To determine the efficiency of a mains transformer.

The method described below is sufficiently accurate for the usual mains type transformer used in radio construction.

Apparatus required.

An A.C. voltage supply capable of supplying all the power required by the windings and a number of wattmeters.

Procedure to Adopt.

The apparatus should be connected as shown in Fig. 175. The power absorbed by the primary and secondary should be observed by reading the wattmeters.

The efficiency of the transformer is expressed as a percentage, i.e. by $\dfrac{\text{output power (watts)}}{\text{input power (watts)}} \times 100$
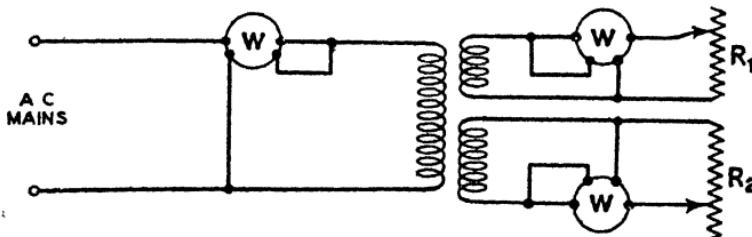
FIG. 175.

The experiment should be made for several loads, say $\frac{1}{4}$, $\frac{1}{2}$, $\frac{3}{4}$ normal and 5/4 above normal load, and a curve plotted showing efficiency as a function of the secondary load.

Conclusions.

The method has two great disadvantages.

1. The energy wasted in the test is considerable depending, of course, upon the size of the transformer windings and the current they normally carry.

2. Accuracy depends entirely upon accurate watt-meters being used, therefore to reduce errors to a minimum great care must be exercised in the reading of the meters.

Expt. 16. *To determine the characteristics of an amplifier.*

To determine the characteristics of an amplifier three tests are usually made:

1. To check the gain or amplification of the amplifier.
2. To ascertain the variation of output over a given frequency range.
3. Stage amplification.

Apparatus Required.

An oscillator, an attenuator, an amplifier, a two-way switch, a valve voltmeter, a high-resistance potentiometer to limit the input voltage to the amplifier, and connecting wire.

Procedure to Adopt.

For the first test the apparatus should be connected as shown in Fig. 176.
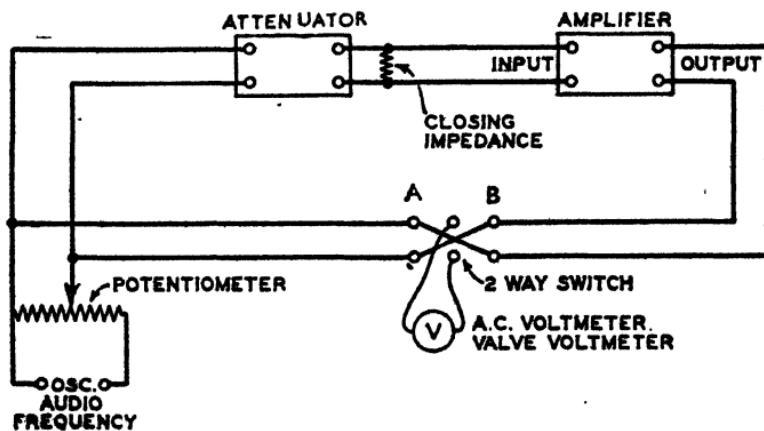
FIG. 176.

The oscillator should be switched on and the input voltage to the amplifier noted by throwing the two-position key to A. This voltage is recorded, after which the switch should be thrown to position B and the output from the amplifier noted.

The voltage amplification $= \dfrac{\text{Output volts}}{\text{Input volts}}$

The amplification is often expressed as gain in decibels

$= 20 \log \dfrac{\text{Output volts}}{\text{Input volts}}$

For the second test the same circuit can be used. Adjust the oscillator output so that the voltmeter reads one volt. This voltage must be maintained at the input side of the oscillator throughout the test.

Throw the switch to position B and note the output.
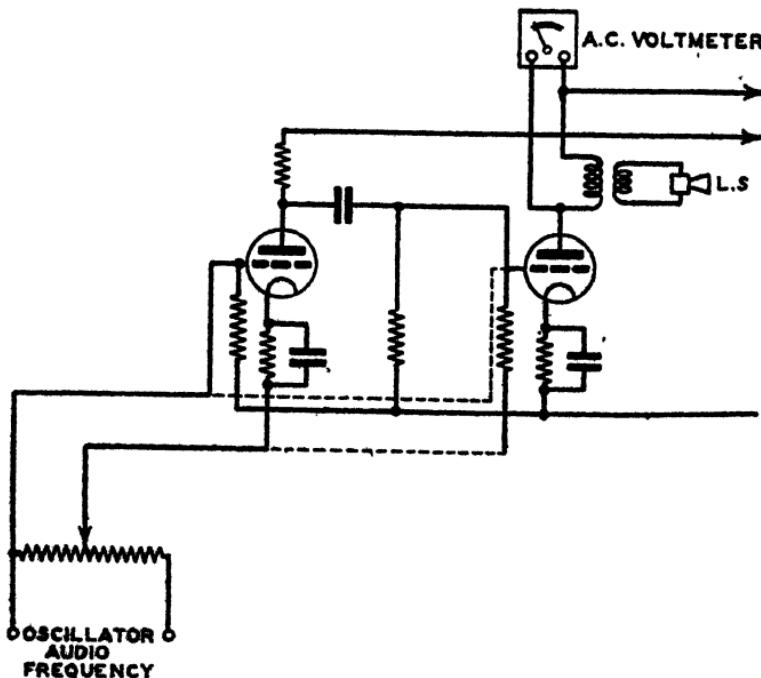
FIG. 177.

The frequency of the oscillator should varied in definite steps of say 50 cps. from 50 cps. to 10,000 cps., and the output and input voltages checked with each change.

Plot a "frequency response" curve using the output voltage as the ordinate and frequency as the abscissa. The response curve of a good amplifier should be fairly flat, i.e., without voltage peaks.

As a final check of an amplifier which is apparently giving satisfactory results the amplification of each stage is measured.

The apparatus should be connected as shown in Fig. 177.

The oscillating signal should be applied between grid and earth of the input valve of the amplifier. Adjust the potentiometer until the voltmeter connected across the output transformer primary reads a suitable voltage. Note this voltage reading, then short circuit the input terminals of the amplifier and apply the same oscillator signal to the grid of the subsequent amplifying valve. Again note the reading on the voltmeter. The first reading in volts divided by the second will give, within reasonable limits, the amplification of the first amplifying stage. Repeat the procedure for subsequent stages. The measured stage amplification should agree, within reasonable limits, with the formula:

$$\text{Amplification per stage} = \frac{\mu z}{r_a + z}$$

where μ is the amplification factor of the valve.

r_a is the A.C. resistance of the valve.

z is the anode load impedance.

Expt. 17. To measure the effective resistance of an inductance coil at radio frequencies.

Apparatus Required.

A radio-frequency oscillator, an inductance coil, a thermo-couple-milliammeter, a known resistance and a condenser.

Procedure.

The radio-frequency oscillator of the required

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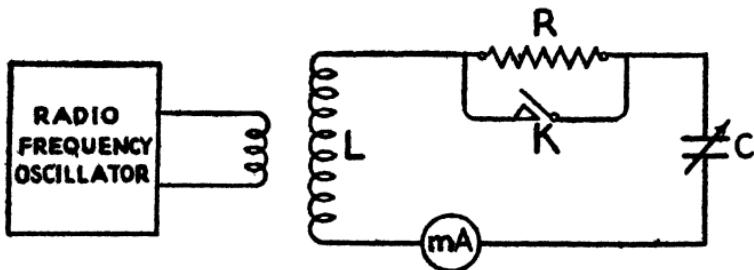
FIG. 178.

frequency is loosely coupled to a circuit consisting of the inductance under test, the milliammeter, the resistance, a key and condenser as shown in Fig. 178.

The circuit is then tuned to resonance by varying the capacitance of the condenser. The current flowing in the milliammeter is then noted first with resistance R short circuited (by depressing key K), and then with resistance R introduced in the circuit.

Let I_1 be the current flowing with resistance short circuit.

Let I_2 be the current flowing with resistance R in circuit.

And R_L be the effective resistance of the circuit.

Then if E is the constant E.M.F. acting in the circuit

$$I_1 = \frac{E}{R_L} \therefore I_1 R_L = E$$

$$\text{and} \quad I_2 = \frac{E}{R + R_L} \therefore I_2 R + I_2 R_L = E$$

$$\therefore I_1 R_L = I_2 R + I_2 R$$

$$\text{and} \quad I_1 R_L - I_2 R_L = I_2 R_L$$

$$\therefore R_L = \frac{I_2 R}{I_1 - I_2}$$

Subtracting from this result the resistance of the thermo-couple heater gives the effective resistance of the inductance coil at the required frequency.

Precautions.

In order to avoid errors it is essential that the coupling between the oscillator and the test circuit be loose.

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Expt. 18. To show how the impedance and power factor of a capacitive circuit vary with the current flowing in the circuit.

Apparatus Required.

An alternating current supply, a non-reactive resistance Rv, a condenser, an A.C. ammeter, a wattmeter and two A.C. voltmeters.

Discussion.

The power factor of the circuit is given by the ratio of the true watts expended to the apparent watts.

Power factor $= \dfrac{W}{VI}$ also the impedance of an A.C. circuit

is given by $Z = \dfrac{V}{I}$

Where V is the total voltage drop in the circuit.
$\quad\quad I$ is the current flowing.
$\quad\quad W$ is the power in watts.
$\quad\quad VI$ is the apparent watts.

Experimental Procedure.

The apparatus should be connected as shown in Fig. 179. By means of Rv the current flowing in the circuit can be adjusted to any desired value. A series of
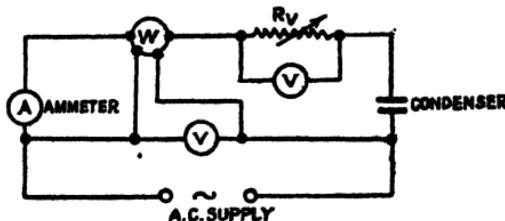
CHECKING THE IMPEDANCE AND POWER
FACTOR OF A CAPACITIVE CIRCUIT

FIG. 179.

current readings I_1, I_2, I_3, etc., should be obtained, and the power and voltages measured for each current reading. These should be recorded in Table 10.

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TABLE 10

Voltage V	Current I	Wattmeter Reading	Power Factor $\dfrac{W}{VI}$	Impedance $\dfrac{V}{I}$

The ratio $\dfrac{W}{VI}$ should always lie between 0 and 1, and may equal one of these limits. With current as the abscissæ graphs should be plotted showing the variation of impedance and power factor with current change. These graphs should take the form shown in Fig. 180.
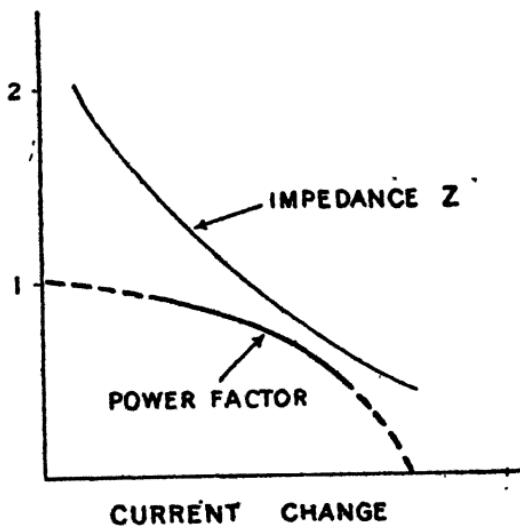
FIG. 180.

Conclusions.

It can be clearly seen from the graph that impedance decreases as the current flowing in the circuit increases. When the current flowing in the circuit is extremely

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small, i.e. when the resistance Rv of the circuit is very large, the power factor tends towards unity, this is because the resistance of the circuit is large compared with the reactance. As the reactance increases with respect to the resistance the power factor drops towards zero. The power factor never reaches absolute zero as every condenser possesses a small amount of resistance.

Expt. 19. To ascertain the value of an unknown resistance by means of the substitution method.

By Ohm's law it is proved that the current flowing in a circuit $I = \dfrac{E}{R_T}$ where E is the electro-motive force and R_T is the total resistance of the circuit. If, therefore, we place a standard ammeter in the circuit containing the unknown resistance Rx and note the current in the circuit and then substitute the unknown resistance by a standard variable resistance Rv and adjust the latter so that the current in the circuit is the same as previously, then the two resistances must be equal. Rv is known, hence we know the value of Rx.

Apparatus Required for the Experiment.

A battery of *very low internal resistance* such as a secondary cell, a two-position switch, the unknown resistance Rx and the standard known variable resistance Rv, a first grade or standard ammeter and connecting wire.

Experimental Procedure.

The apparatus should be connected as shown in Fig. 181.

With the key connected to position A, the current flowing in the ammeter should be recorded I_1. This completed the key should be thrown to position B and the standard variable resistance adjusted until the current flowing in the circuit is equal to I_1. Under these conditions Rx equals Rv, the value of the latter being ascertained from the reading of the dials.

Millammeter
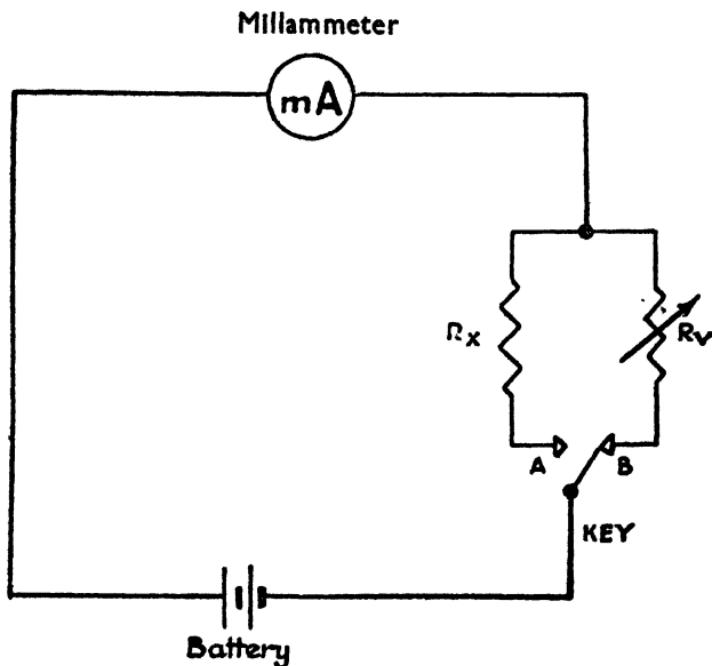
MEASURING A RESISTANCE BY THE
SUBSTITUTION METHOD

FIG. 181.

Conclusions.

The accuracy of the experiment depends upon three things.

1. The accuracy of the ammeter, and the accuracy to which it can be read.

2. The accuracy and fineness of adjustment of the variable resistance.

3. The internal resistance of the battery must be low compared with the resistance being measured, or at least have a constant value.

Expt. 20. To ascertain the condition of a cell or primary battery.

The two main disadvantages of primary cells or

batteries are that they suffer from polarisation and local action. For example, place a voltmeter across the terminals of a battery, and from the voltage reading obtained you may be led to believe the cell is satisfactory, but give it some work to do, and you may find that the voltage of the cell quickly drops. This is probably due to one of the troubles mentioned above, nearly always polarisation. This experiment shows a simple check which may be given to a cell to ascertain its condition.

Apparatus Required.

The battery or cell to be tested, a first grade voltmeter, a 2-ohm resistance, two keys K_1, K_2, and connecting wire.

Experimental Procedure.

The apparatus should be connected as shown in Fig. 182. Depress the key K_1 and note the open circuit voltage V_1. Now depress the key K_2 and immediately
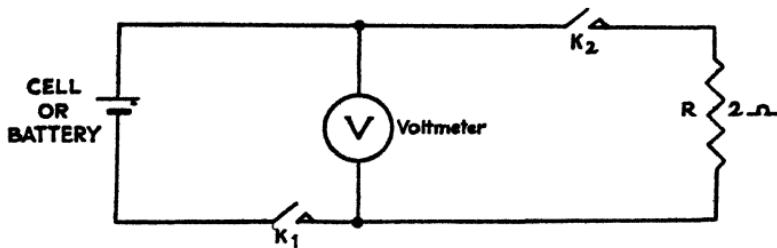
ASCERTAINING THE CONDITION OF A CELL

FIG. 182.

note the voltage V_2. Keep both keys depressed for one minute at the end of which take a third voltage reading V_3. These three voltage readings give an accurate picture of the condition of the cell or battery. If the third voltage reading is lower than 1 volt, the cell is unfit for further use.

NOTE.—If the battery consists of a number of cells connected in series, 2 ohms resistance should be added

to R for each cell so connected, and the final voltage reading should not be less than 1 volt per cell.

Conclusions.

This method of testing the conditions of cells or batteries is adopted universally as being the easiest and most reliable method.

Expt. 21. To measure the power factor of a condenser.

The power factor of a condenser can be likened to the effect of a small resistance placed in series with the condenser or a large resistance connected in parallel. Power factor (Cos θ) is equal to ωCR, where C is the capacity in farads and R is the loss resistance. Power factor is also given by the ratio of the true power divided by the apparent power.

Apparatus Required.

A standard condenser of known capacity C and negligible power factor, a low (standard non-inductive) variable resistance (r), the condenser whose power factor is to be measured (K), two non-inductive ratio arms PQ, headphones and an oscillator.

Procedure to be Adopted.

The apparatus should be connected as shown in Fig. 183. With an unbalanced bridge a tone is heard in the headphones. By adjustment of the standard condenser C, and the resistance r, balance of the bridge is obtained, at which point the tone in the headphones is a minimum. When the balance is obtained the impedance of the condenser K is proportional to that of the adjustable arm containing the standard condenser C and resistance r.

With equal ratio arms the known capacity C is equal to the capacity of the unknown capacity K; and the power factor Cos θ, is given by ωCr.

Discussion.

The phase difference and hence the power factor, depends largely on the materials used in the make up
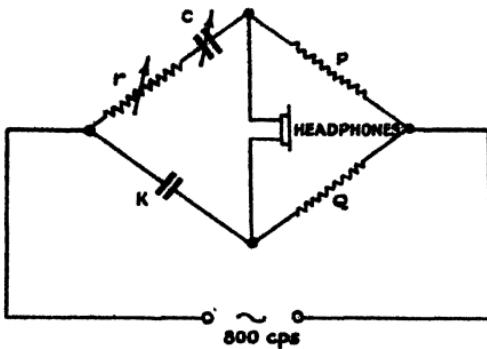
MEASURING THE POWER FACTOR OF A
CONDENSER

Fig. 183.

of a condenser, and particularly, in the case of paper
condensers, on the dryness of the paper. An average
paper condenser has a phase angle difference of about
10 minutes, or a power factor of 0·0027. The efficiency
of a good condenser is thus very high, about 99·7 per
cent. In a poor condenser the phase difference may
rise to about 22° or a power factor of 0·37. Condensers
constructed of mica can easily be made having a phase
difference of only one minute.

Expt. 22. The measurement of mutual inductance.

Apparatus Required.

A variable mutual inductance M, a detector such as
headphones or vibrating galvanometer and the un-
known mutual inductance M_1.

Procedure to Adopt.

Connect the apparatus up as shown in Fig. 184. M_1
is connected to M so that their primary coils P_1 and P
are in series with each other and an alternating source,
while the secondaries S_1 and S with their windings in
opposition are connected to a detector G, such as a
vibration galvanometer or a telephone. M is then

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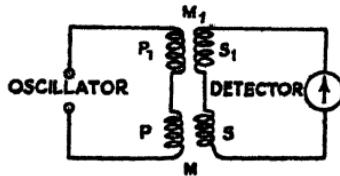
**MEASUREMENT OF INDUCTANCE-
OPPOSITION METHOD**

FIG. 184.

adjusted until a balance is obtained, the detector indicating that the secondary current is zero.

Then $M_1 = M$.

M_1 should be a considerable distance from M, and if possible, it should be so placed as to have zero mutual inductance to it. Readings should be taken with reversal of leads going to P_1 and S_1 respectively. Readings should also be taken with the leads to P_1 and S_1 joined in their circuits so as to exclude M_1. S should be reversed, and a balance obtained. The reading of M then gives the value of the mutual inductance between the leads, and hence a correction may be made.

NOTE.

1. For frequencies up to 300 cycles per second, a vibration galvanometer is usually more sensitive than headphones.

2. The value of the unknown mutual inductance must lie within the range of the Standard Variable Mutual Inductance.

Conclusion.

The method is simple and efficient. If an alternating current supply is not available, direct current may be used, interrupted or reversed by a key, and a ballistic galvanometer then forms a suitable detector.

TABLES AND DATA

TABLE 1

GREEK LETTERS AND THEIR TECHNICAL DESIGNATIONS

Name.	Letters Capital. (c)	Letters Small. (s)	Commonly used to Designate.
Alpha	A	α	Areas, Attenuation Constant.
Beta	B	β	Angles, Coefficients, Wavelength Constant.
Gamma	Γ	γ	Conductivity, Propogation Constant.
Delta	Δ	δ	Increments, Decriments, Variation.
Epsilon	E	ϵ	E.m.f. Base of Natural Logarithms.
Zeta	Z	ζ	(c) Impedance.
Eta	H	η	(c) Magnetic Field Strength, Efficiency.
Theta	Θ	θ	Angles, Angular Phase Displacement.
Iota	I		Current Flow.
Kappa	K	κ	Susceptibility, Dielectric Constant or Permittivity.
Lambda	Λ	λ	Wavelength.
Mu	M	μ	(s) Amplification Factor, Prefix for micro-.
Pi	Π	π	Circumference Divided by Diameter ($3 \cdot 1416$).
Rho	P	ρ	(s) Specific Resistance or Resistivity.
Sigma	Σ	σ	(c) Sign of Summation.
Tau	T	τ	Time Constant.
Phi	Φ	ϕ	(c) Flux, Angle of Lag or Lead.
Chi	X	χ	(c) Reactance.
Psi	Ψ	ψ	Dielectric Flux, Phase Difference.
Omega	Ω	ω	(c) Resistance in ohms. (s) Angular Velocity $2\pi f$.

TABLE 2

IMPEDANCE AND ADMITTANCE FORMULAE FOR A.C CIRCUITS.

Circuit Arrangement	Impedance		Resistance	Reactance	Admittance		Conductance	Susceptance
	Z	ϕ	r	jx	Y	θ	g	jb
R ohms	R	0	R	0	$\frac{1}{R}$	0	$\frac{1}{R}$	0
L henries	ωL	$\frac{\pi}{2}$	0	ωL	$\frac{1}{\omega L}$	$-\frac{\pi}{2}$	0	$-\frac{1}{\omega L}$
C farads	$\frac{1}{\omega C}$	$-\frac{\pi}{2}$	0	$-\frac{1}{\omega C}$	ωC	$\frac{\pi}{2}$	0	ωC
G mhos	$\frac{1}{G}$	0	$\frac{1}{G}$	0	G	0	G	0
				If $r=0$ and $x=0$ then $g=\infty$ and $b=\infty$				
R—L	$\sqrt{R^2+\omega^2L^2}$	$Tan^{-1}\frac{\omega L}{R}$	R	ωL	$\frac{1}{\sqrt{R^2+\omega^2L^2}}$	$-Tan^{-1}\frac{\omega L}{R}$	$\frac{R}{R^2+\omega^2L^2}$	$-\frac{\omega L}{R^2+\omega^2L^2}$
G—C	$\frac{1}{\sqrt{G^2+\omega^2C^2}}$	$-Tan^{-1}\frac{\omega C}{G}$	$\frac{G}{G^2+\omega^2C^2}$	$-\frac{\omega C}{G^2+\omega^2C^2}$	$\sqrt{G^2+\omega^2C^2}$	$Tan^{-1}\frac{\omega C}{G}$	G	ωC
R—C	$\frac{\sqrt{1+\omega^2C^2R^2}}{\omega C}$	$-Tan^{-1}\frac{1}{\omega CR}$	R	$-\frac{1}{\omega C}$	$\frac{\omega C}{\sqrt{1+\omega^2C^2R^2}}$	$Tan^{-1}\frac{1}{\omega CR}$	$\frac{\omega^2C^2R}{1+\omega^2C^2R^2}$	$\frac{\omega C}{1+\omega^2C^2R^2}$
L—C (series)	$\frac{\omega^2LC-1}{\omega C}$	$\frac{\pi}{2}\text{ OR }-\frac{\pi}{2}$	0	$\frac{\omega^2LC-1}{\omega C}$	$\frac{\omega C}{\omega^2LC-1}$	$-\frac{\pi}{2}\text{ OR }\frac{\pi}{2}$	0	$-\frac{\omega C}{\omega^2LC-1}$
				If $\omega^2LC=1$ then $Z=0$ and $Y=\infty$				
L—C (parallel)	$\frac{\omega L}{\omega^2LC-1}$	$\frac{\pi}{2}\text{ OR }-\frac{\pi}{2}$	0	$-\frac{\omega L}{\omega^2LC-1}$	$\frac{\omega^2LC-1}{\omega L}$	$-\frac{\pi}{2}\text{ OR }\frac{\pi}{2}$	0	$\frac{\omega^2LC-1}{\omega L}$
				If $\omega^2LC=1$ then $Z=\infty$ and $Y=0$				
R—L—C	$\sqrt{R^2+\left(\frac{\omega^2LC-1}{\omega C}\right)^2}$	$Tan^{-1}\frac{\omega^2LC-1}{R\omega C}$	R	$\frac{\omega^2LC-1}{\omega C}$	$\frac{1}{\sqrt{R^2+\left(\frac{\omega^2LC-1}{\omega C}\right)^2}}$	$-Tan^{-1}\frac{\omega^2LC-1}{R\omega C}$	$\frac{R}{R^2+\left(\frac{\omega^2LC-1}{\omega C}\right)^2}$	$-\frac{(\omega^2LC-1)}{\omega C\left[R^2+\left(\frac{\omega^2LC-1}{\omega C}\right)^2\right]}$
		$-Tan^{-1}\frac{\omega L(\omega^2LC-1)+\omega CR^2}{R}$	$\frac{R}{(1-\omega^2LC)^2+\omega^2C^2R^2}$	$\frac{\omega L(1-\omega^2LC)-\omega CR^2}{(1-\omega^2LC)^2+\omega^2C^2R^2}$				$\frac{[\omega L(\omega^2LC-1)+\omega CR^2]}{R^2+\omega^2L^2}$
R—L—R₁	$R_1\sqrt{\frac{R^2+\omega^2L^2}{(R+R_1)^2+\omega^2L^2}}$	$Tan^{-1}\frac{\omega L R_1}{R(R+R_1)+\omega^2L^2}$	$\frac{R_1[R(R+R_1)+\omega^2L^2]}{(R+R_1)^2+\omega^2L^2}$	$\frac{\omega L R_1^2}{(R+R_1)^2+\omega^2L^2}$	$\frac{1}{R_1}\sqrt{\frac{(R+R_1)^2+\omega^2L^2}{R^2+\omega^2L^2}}$	$-Tan^{-1}\frac{\omega L R_1}{R(R+R_1)+\omega^2L^2}$	$\frac{R(R+R_1)+\omega^2L^2}{R_1(R^2+\omega^2L^2)}$	$-\frac{\omega L R_1}{R_1(R^2+\omega^2L^2)}$

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TABLE 3

POWER RATIOS TO DECIBELS.

Power Ratio	db.	Power Ratio	db.	Power Ratio	db.	Power Ratio	db.	Power Ratio	db.
1·0	0·00	10	10·00	100	20·00	1,000	30·00	10^4	40
1·5	1·76	15	11·76	150	21·76	1,500	31·76	10^5	50
2·0	3·01	20	13·01	200	23·01	2,000	33·01	10^6	60
2·5	3·98	25	13·98	250	23·98	2,500	33·98	10^7	70
3·0	4·77	30	14·77	300	24·77	3,000	34·77	10^8	80
3·5	5·44	35	15·44	350	25·44	3,500	35·44	10^9	90
4·0	6·02	40	16·02	400	26·02	4,000	36·02	10^{10}	100
4·5	6·53	45	16·53	450	26·53	4,500	36·53		
5·0	6·99	50	16·99	500	26·99	5,000	36·99		
5·5	7·40	55	17·40	550	27·40	5,500	37·40		
6·0	7·78	60	17·78	600	27·78	6,000	37·78		
6·5	8·13	65	18·13	650	28·13	6,500	38·13		
7·0	8·45	70	18·45	700	28·45	7,000	38·45		
7·5	8·75	75	18·75	750	28·75	7,500	38·75		
8·0	9·03	80	19·03	800	29·03	8,000	39·03		
8·5	9·29	85	19·29	850	29·29	8,500	39·29		
9·0	9·54	90	19·54	900	29·54	90,00	39·54		
9·5	9·78	95	19·78	950	29·78	95,00	39·78		

Conversion Factor 8·686 Decibels = 1 Neper.

TABLE 4

RESISTOR COLOUR CODE

0	Black	5	Green
1	Brown	6	Blue
2	Red	7	Violet
3	Orange	8	Grey
4	Yellow	9	White
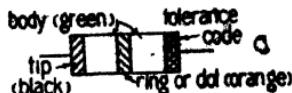
The colour code o to 9 is represented by colour changes from black to white and the order over part of the range is the same as that of the colours of the spectrum.

The first two figures of the resistor value are indicated by the body and tip respectively, and the number of noughts following by the ring. The example is 50,000 ohms.

VALVE SYMBOLS

Diode or Half-wave rectifier

Double-diode or Full-wave rectifier

Triode

Double-diode triode

Screened grid or tetrode

Pentode
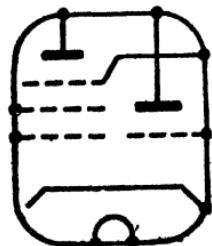
Triode - pentode
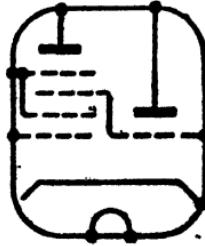
Triode - hexode

Double triode

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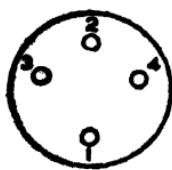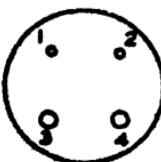
VALVE BASES

4 Pin

Small
4 Pin
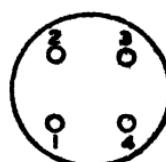
American
4 Pin
(Bayonet
catch)
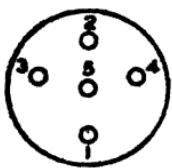
5 Pin
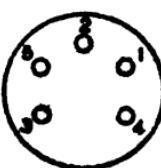
Small
5 Pin

7 Pin

American
or
International
Octal.
Mazda
Octal.
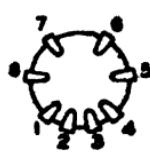
Side
contact
8 Pin
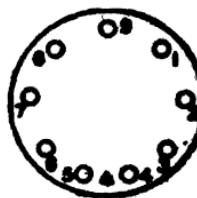
9 Pin

Note.—The view is of the valve base itself, or of the underside of the valve holder.

TABLE 5
VALVE BASES

When more than one grid is employed the grid nearest the cathode is referred to as the "first grid," the next is the "second grid," etc. In tetrodes the first grid is normally the control grid and the second the screen grid. In pentodes the first grid is normally the control grid, the second the screen grid and the third the suppressor grid.

4 Pin.

Base	TC	1	2	3	4
4A	—	A	G	F	F
4E	—	A	A	F	F
4K	DA	C	—	H	H
Sm 4A	—	A	G	F	F

American 4 Pin (Bayonet Catch).

Base†	1	2	3	4
A4	G	F	F	A

5 Pin.

Base	TC	1	2	3	4	5
5A	—	A	G	H	H	C
5B	A	Ge	G1	H	H	C
5F	—	A	G1	F	F	G2
5H	—	A	A	H	H	C
Sm 5A	—	A	G1	F	F	G 2

7 Pin.

Base†	TC	1	2	3	4	5	6	7
7B	G1	OA	G3, OG	G2, G4	H	H	C	A
7D	A	M	G1	G3	H	H	C	G2
7E	G1	M	A	G3	H	H	C	G2
7F	G	M	—	—	H	H	C	A
7J	—	—	G1	G2	H	H	C	A
7K	—	G2	G1	A1	F	F	C	A2
7O	—	G3	G1	G2	H	H	C	A
7Q	G1	—	—	G2	H	H	G3, C	A

† In agreement with the numbering on the valve holder.

8 Pin.

Base	TC	1	2	3	4	5	6	6	8
A8C	G1	M	H	A	G2	G3	—	H	C
A8E	G1	M	H	A	DA	DA	—	H	C
A8G	—	—	H	A	—	G	—	H	C
A8O	G	—	F	A	—	DA	—	F	—
A8Y	—	—	F	A	G2	G1	—	F	Centre filament
A8 AC	—	—	H	—	—	A	—	H	C
MO 82	A	H, C	—	—	—	—	—	—	H
MO 813	G1	H	C	A	G2	G3	M	—	H
Ct 8B	G1	M	H	H	C	G3	—	G2	H
Ct 8L	G1	M	H	H	C	G4	G2	G3	A

A8 = American or International Octal. MO 8 = Mazda Octal.
Ct 8 = Side contact 8 Pin.

TABLE 5. VALVE BASES (*continued*).

9 PIN.

Base	TC	1	2	3	4	5	6	7	8	9
9B	G1	G2	A	G3	H	H	C	OA	OG	M

FREQUENCY/AERIAL LENGTH NOMOGRAM
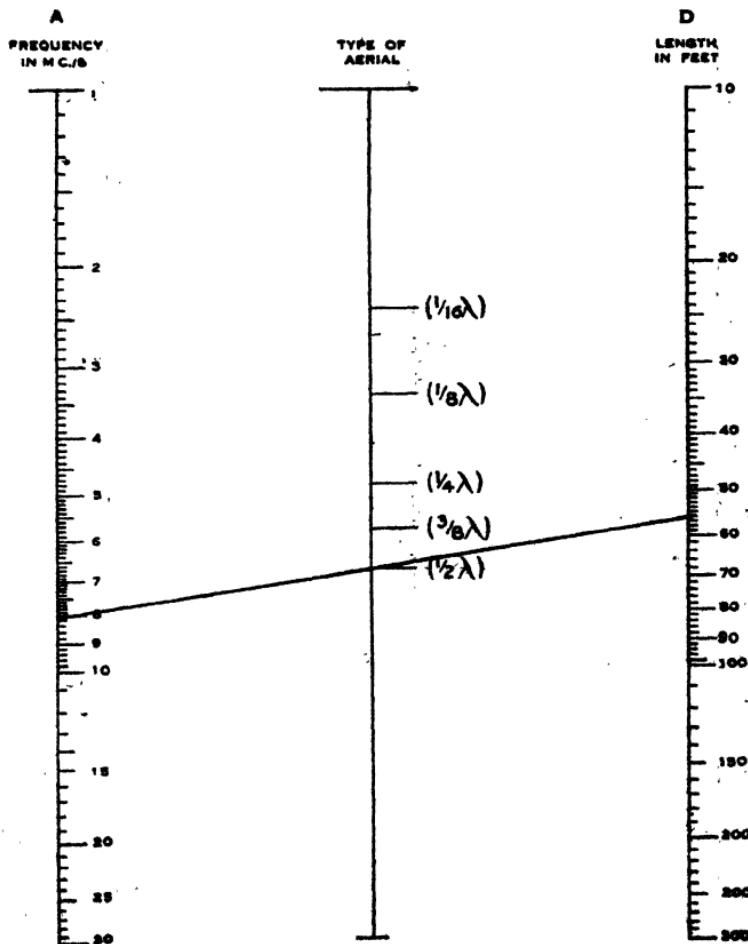
NOMOGRAM SHOWING RANGES OF SURFACE RAY
RADIATED OVER SEA
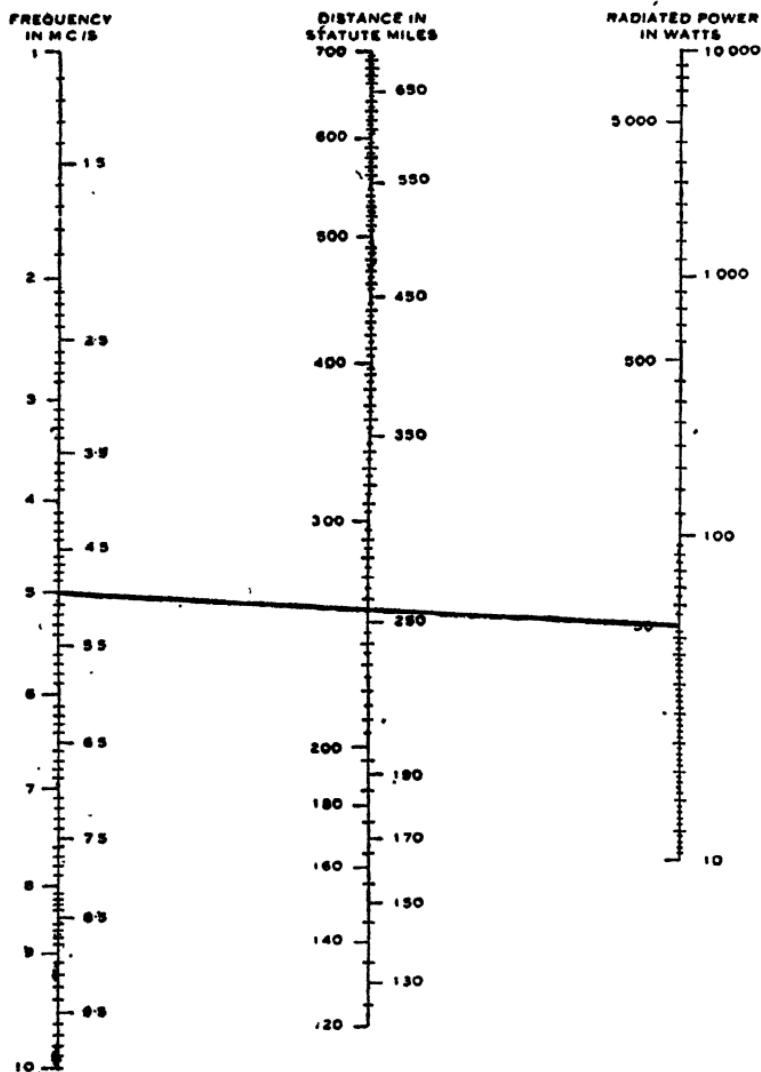
NOMOGRAM

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NOMOGRAM SHOWING RANGES OF SURFACE RAY RADIATED OVER SEA
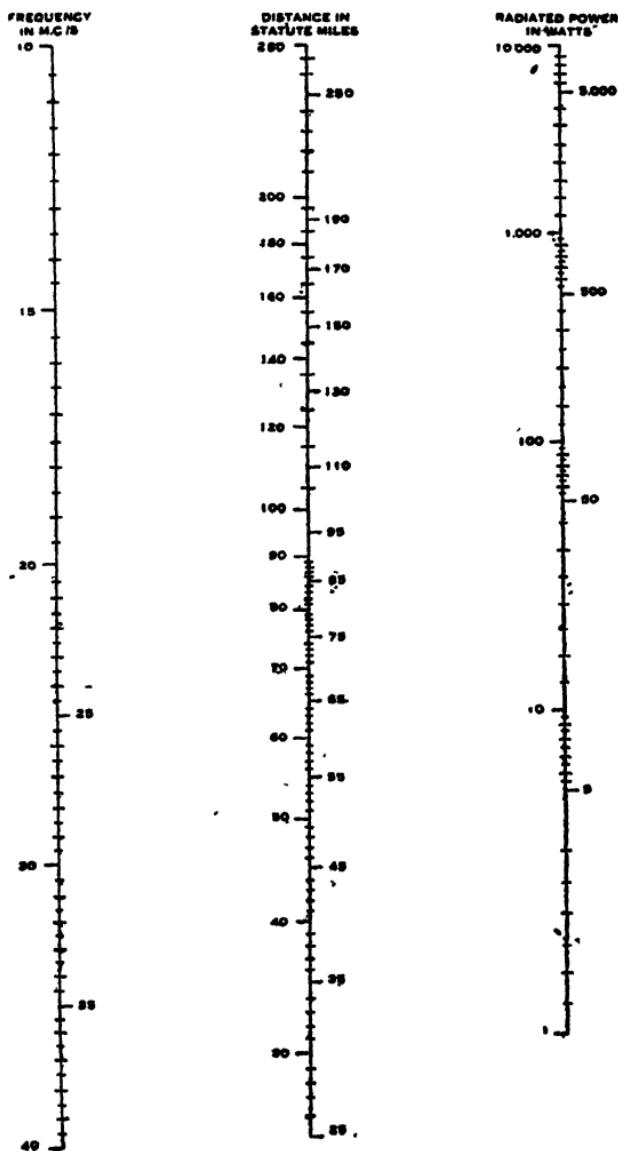
SPECTRUM UTILISATION CHART.

FREQUENCY, CYCLES PER SECOND		WAVELENGTH
10^{20}	X-RAYS MILLION VOLT	
	X-RAYS "HARD"	1X
10^{19}	X-RAYS "DIAGNOSTIC"	
		1X
10^{18}		
	X-RAYS "INDUSTRIAL"	10Å
10^{17}		
	X-RAYS "SOFT"	100Å
10^{16}		
		1000Å
10^{15}	ULTRA-VIOLET RAYS	
	VISIBLE LIGHT	1µ
10^{14}	INFRA RED	
		10µ
10^{13}		
		100µ
10^{12}		
	UNBRIDGED BAND	1mm
10^{11}		
		1cm
10^{10}	RADIO- CENTIMETRE BAND	
		10cm
10^{9}	RADIO DECIMETRE BAND	
		1m
10^{8}	RADIO METRE BAND TELEVISION RELAY	
	UHF & FM BROADCASTING	10m
10^{7}	RADIO "SHORT WAVE" BAND	
		100m
10^{6}	RADIO "MEDIUM WAVE" BAND (BROADCASTING)	
	RADIO MARINE S.O.S.	
	RADIO LONG WAVE BAND (BROADCASTING)	1000m
10^{5}	RADIO NAVIGATION AIDS (PRE-WAR)	
	SUPERSONIC REGION	10000m
10^{4}		
10^{3}	AUDIO FREQUENCIES	
10^{2}		
10	POWER DISTRIBUTION FREQUENCIES	

NOTE: WAVELENGTH UNITS INDICATED ARE METRES,
CENTIMETRES, MILLIMETRES, MICRONS (µ),
AND ANGSTROMS.

(By permission of the British Institute of Radio Engineers).

TABLE 6. LOGARITHMS

	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
10	0000	0043	0086	0128	0170	0212	0253	0294	0334	0374	4	8	12	17	21	25	29	33	37
11	0414	0453	0492	0531	0569	0607	0645	0682	0719	0755	4	8	11	15	19	23	26	30	34
12	0792	0828	0864	0899	0934	0969	1004	1038	1072	1106	3	7	10	14	17	21	24	28	31
13	1139	1173	1206	1239	1271	1303	1335	1367	1399	1430	3	6	10	13	16	19	23	26	29
14	1461	1492	1523	1553	1584	1614	1644	1673	1703	1732	3	6	9	12	15	18	21	24	27
15	1761	1790	1818	1847	1875	1903	1931	1959	1987	2014	3	6	8	11	14	17	20	22	25
16	2041	2068	2095	2122	2148	2175	2201	2227	2253	2279	3	5	8	11	13	16	18	21	24
17	2304	2330	2355	2380	2405	2430	2455	2480	2504	2529	2	5	7	10	12	15	17	20	22
18	2553	2577	2601	2625	2648	2672	2695	2718	2742	2765	2	5	7	9	12	14	16	19	21
19	2788	2810	2833	2856	2878	2900	2923	2945	2967	2989	2	4	7	9	11	13	16	18	20
20	3010	3032	3054	3075	3096	3118	3139	3160	3181	3201	2	4	6	8	11	13	15	17	19
21	3222	3243	3263	3284	3304	3324	3345	3365	3385	3404	2	4	6	8	10	12	14	16	18
22	3424	3444	3464	3483	3502	3522	3541	3560	3579	3598	2	4	6	8	10	12	14	15	17
23	3617	3636	3655	3674	3692	3711	3729	3747	3766	3784	2	4	6	7	9	11	13	15	17
24	3802	3820	3838	3856	3874	3892	3909	3927	3945	3962	2	4	5	7	9	11	12	14	16
25	3979	3997	4014	4031	4048	4065	4082	4099	4116	4133	2	3	5	7	9	10	12	14	15
26	4150	4166	4183	4200	4216	4232	4249	4265	4281	4298	2	3	5	7	8	10	11	13	15
27	4314	4330	4346	4362	4378	4393	4409	4425	4440	4456	2	3	5	6	8	9	11	13	14
28	4472	4487	4502	4518	4533	4548	4564	4579	4594	4609	2	3	5	6	8	9	11	12	14
29	4624	4639	4654	4669	4683	4698	4713	4728	4742	4757	1	3	4	6	7	9	10	12	13
30	4771	4786	4800	4814	4829	4843	4857	4871	4886	4900	1	3	4	6	7	9	10	11	13
31	4914	4928	4942	4955	4969	4983	4997	5011	5024	5038	1	3	4	6	7	8	10	11	12
32	5051	5065	5079	5092	5105	5119	5132	5145	5159	5172	1	3	4	5	7	8	9	11	12
33	5185	5198	5211	5224	5237	5250	5263	5276	5289	5302	1	3	4	5	6	8	9	10	12
34	5315	5328	5340	5353	5366	5378	5391	5403	5416	5428	1	3	4	5	6	8	9	10	11
35	5441	5453	5465	5478	5490	5502	5514	5527	5539	5551	1	2	4	5	6	7	9	10	11
36	5563	5575	5587	5599	5611	5623	5635	5647	5658	5670	1	2	4	5	6	7	8	10	11
37	5682	5694	5705	5717	5729	5740	5752	5763	5775	5786	1	2	3	5	6	7	8	9	10
38	5798	5809	5821	5832	5843	5855	5866	5877	5888	5899	1	2	3	5	6	7	8	9	10
39	5911	5922	5933	5944	5955	5966	5977	5988	5999	6010	1	2	3	4	5	7	8	9	10
40	6021	6031	6042	6053	6064	6075	6085	6096	6107	6117	1	2	3	4	5	6	8	9	10
41	6128	6138	6149	6160	6170	6180	6191	6201	6212	6222	1	2	3	4	5	6	7	8	9
42	6232	6243	6253	6263	6274	6284	6294	6304	6314	6325	1	2	3	4	5	6	7	8	9
43	6335	6345	6355	6365	6375	6385	6395	6405	6415	6425	1	2	3	4	5	6	7	8	9
44	6435	6444	6454	6464	6474	6484	6493	6503	6513	6522	1	2	3	4	5	6	7	8	9
45	6532	6542	6551	6561	6571	6580	6590	6599	6609	6618	1	2	3	4	5	6	7	8	9
46	6628	6637	6646	6656	6665	6675	6684	6693	6702	6712	1	2	3	4	5	6	7	7	8
47	6721	6730	6739	6749	6758	6767	6776	6785	6794	6803	1	2	3	4	5	5	6	7	8
48	6812	6821	6830	6839	6848	6857	6866	6875	6884	6893	1	2	3	4	4	5	6	7	8
49	6902	6911	6920	6928	6937	6946	6955	6964	6972	6981	1	2	3	4	4	5	6	7	8
50	6990	6998	7007	7016	7024	7033	7042	7050	7059	7067	1	2	3	3	4	5	6	7	8
51	7076	7084	7093	7101	7110	7118	7126	7135	7143	7152	1	2	3	3	4	5	6	7	8
52	7160	7168	7177	7185	7193	7202	7210	7218	7226	7235	1	2	2	3	4	5	6	7	7
53	7243	7251	7259	7267	7275	7284	7292	7300	7308	7316	1	2	2	3	4	5	6	6	7
54	7324	7332	7340	7348	7356	7364	7372	7380	7388	7396	1	2	2	3	4	5	6	6	7

Hyperbolic Logarithms = Common Logarithms × 2·30258.

LOGARITHMS (continued)

	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
55	7404	7412	7419	7427	7435	7443	7451	7459	7466	7474	1	2	3	3	4	5	5	6	7
56	7482	7490	7497	7505	7513	7520	7528	7536	7543	7551	1	2	2	3	4	5	5	6	7
57	7559	7566	7574	7582	7589	7597	7604	7612	7619	7627	1	2	2	3	4	5	5	6	7
58	7634	7642	7649	7657	7664	7672	7679	7686	7694	7701	1	1	2	3	4	4	5	6	7
59	7709	7716	7723	7731	7738	7745	7752	7760	7767	7774	1	1	2	3	4	4	5	6	7
60	7782	7789	7796	7803	7810	7818	7825	7832	7839	7846	1	1	2	3	4	4	5	6	6
61	7853	7860	7868	7875	7882	7889	7896	7903	7910	7917	1	1	2	3	4	4	5	6	6
62	7924	7931	7938	7945	7952	7959	7966	7973	7980	7987	1	1	2	3	3	4	5	6	6
63	7993	8000	8007	8014	8021	8028	8035	8041	8048	8055	1	1	2	3	3	4	5	5	6
64	8062	8069	8075	8082	8089	8096	8102	8109	8116	8122	1	1	2	3	3	4	5	5	6
65	8129	8136	8142	8149	8156	8162	8169	8176	8182	8189	1	1	2	3	3	4	5	5	6
66	8195	8202	8209	8215	8222	8228	8235	8241	8248	8254	1	1	2	3	3	4	5	5	6
67	8261	8267	8274	8280	8287	8293	8299	8306	8312	8319	1	1	2	3	3	4	5	5	6
68	8325	8331	8338	8344	8351	8357	8363	8370	8376	8382	1	1	2	3	3	4	5	5	6
69	8388	8395	8401	8407	8414	8420	8426	8432	8439	8445	1	1	2	2	3	4	4	5	6
70	8451	8457	8463	8470	8476	8482	8488	8494	8500	8506	1	1	2	2	3	4	4	5	6
71	8513	8519	8525	8531	8537	8543	8549	8555	8561	8567	1	1	2	2	3	4	4	5	5
72	8573	8579	8585	8591	8597	8603	8609	8615	8621	8627	1	1	2	2	3	4	4	5	5
73	8633	8639	8645	8651	8657	8663	8669	8675	8681	8686	1	1	2	2	3	4	4	5	5
74	8692	8698	8704	8710	8716	8722	8727	8733	8739	8745	1	1	2	2	3	4	4	5	5
75	8751	8756	8762	8768	8774	8779	8785	8791	8797	8802	1	1	2	2	3	3	4	5	5
76	8808	8814	8820	8825	8831	8837	8842	8848	8854	8859	1	1	2	2	3	3	4	5	5
77	8865	8871	8876	8882	8887	8893	8899	8904	8910	8915	1	1	2	2	3	3	4	4	5
78	8921	8927	8932	8938	8943	8949	8954	8960	8965	8971	1	1	2	2	3	3	4	4	5
79	8976	7982	8987	8993	8998	9004	9009	9015	9020	9025	1	1	2	2	3	3	4	4	5
80	9031	9036	9042	9047	9053	9058	9063	9069	9074	9079	1	1	2	2	3	3	4	4	5
81	9085	9090	9096	9101	9106	9112	9117	9122	9128	9133	1	1	2	2	3	3	4	4	5
82	9138	9143	9149	9154	9159	9165	9170	9175	9180	9186	1	1	2	2	3	3	4	4	5
83	9191	9196	9201	9206	9212	9217	9222	9227	9232	9238	1	1	2	2	3	3	4	4	5
84	9243	9248	9253	9258	9263	9269	9274	9279	9284	9289	1	1	2	2	3	3	4	4	5
85	9294	9299	9304	9309	9315	9320	9325	9330	9335	9340	1	1	2	2	3	3	4	4	5
86	9345	9350	9355	9360	9365	9370	9375	9380	9385	9390	1	1	2	2	3	3	4	4	4
87	9395	9400	9405	9410	9415	9420	9425	9430	9435	9440	0	1	1	2	2	3	3	4	4
88	9445	9450	9455	9460	9465	9469	9474	9479	9484	9489	0	1	1	2	2	3	3	4	4
89	9494	9499	9504	9509	9513	9518	9523	9528	9533	9538	0	1	1	2	2	3	3	4	4
90	9542	9547	9552	9557	9562	9566	9571	9576	9581	9586	0	1	1	2	2	3	3	4	4
91	9590	9595	9600	9605	9609	9614	9619	9624	9628	9633	0	1	1	2	2	3	3	4	4
92	9638	9643	9647	9652	9657	9661	9666	9671	9675	9680	0	1	1	2	2	3	3	4	4
93	9685	9689	9694	9699	9703	9708	9713	9717	9722	9727	0	1	1	2	2	3	3	4	4
94	9731	9736	9741	9745	9750	9754	9759	9763	9768	9773	0	1	1	2	2	3	3	4	4
95	9777	9782	9786	9791	9795	9800	9805	9809	9814	9818	0	1	1	2	2	3	3	4	4
96	9823	9827	9832	9836	9841	9845	9850	9854	9859	9863	0	1	1	2	2	3	3	4	4
97	9868	9872	9877	9881	9886	9890	9894	9899	9903	9908	0	1	1	2	2	3	3	4	4
98	9912	9917	9921	9926	9930	9934	9939	9943	9948	9952	0	1	1	2	2	3	3	4	4
99	9956	9961	9965	9969	9974	9978	9983	9987	9991	9996	0	1	1	2	2	3	3	3	4

Common Logarithms = Hyperbolic Logarithms × 0·43429.

TABLE 7. ANTILOGARITHMS

	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
·00	1000	1002	1005	1007	1009	1012	1014	1016	1019	1021	0	0	1	1	1	1	2	2	2
·01	1023	1026	1028	1030	1033	1035	1038	1040	1042	1045	0	0	1	1	1	1	2	2	2
·02	1047	1050	1052	1054	1057	1059	1062	1064	1067	1069	0	0	1	1	1	1	2	2	2
·03	1072	1074	1076	1079	1081	1084	1086	1089	1091	1094	0	0	1	1	1	1	2	2	2
·04	1095	1099	1102	1104	1107	1109	1112	1114	1117	1119	0	1	1	1	1	2	2	2	2
·05	1122	1125	1127	1130	1132	1135	1138	1140	1143	1146	0	1	1	1	1	2	2	2	2
·06	1148	1151	1153	1156	1159	1161	1164	1167	1169	1172	0	1	1	1	1	2	2	2	2
·07	1175	1178	1180	1183	1186	1189	1191	1194	1197	1199	0	1	1	1	1	2	2	2	2
·08	1202	1205	1208	1211	1213	1216	1219	1222	1225	1227	0	1	1	1	1	2	2	2	3
·09	1230	1233	1236	1239	1242	1245	1247	1250	1253	1256	0	1	1	1	1	2	2	2	3
·10	1259	1262	1265	1268	1271	1274	1276	1279	1282	1285	0	1	1	1	1	2	2	2	3
·11	1288	1291	1294	1297	1300	1303	1306	1309	1312	1315	0	1	1	1	2	2	2	2	3
·12	1318	1321	1324	1327	1330	1334	1337	1340	1343	1346	0	1	1	1	2	2	2	3	3
·13	1349	1352	1355	1358	1361	1365	1368	1371	1374	1377	0	1	1	1	2	2	2	3	3
·14	1380	1384	1387	1390	1393	1396	1400	1403	1406	1409	0	1	1	1	2	2	2	3	3
·15	1413	1416	1419	1422	1426	1429	1432	1435	1439	1442	0	1	1	1	2	2	2	3	3
·16	1445	1449	1452	1455	1459	1462	1466	1469	1472	1476	0	1	1	1	2	2	2	3	3
·17	1479	1483	1486	1489	1493	1496	1500	1503	1507	1510	0	1	1	1	2	2	2	3	3
·18	1514	1517	1521	1524	1528	1531	1535	1538	1542	1545	0	1	1	1	2	2	2	3	3
·19	1549	1552	1556	1560	1563	1567	1570	1574	1578	1581	0	1	1	1	2	2	3	3	3
·20	1585	1589	1592	1596	1600	1603	1607	1611	1614	1618	0	1	1	1	2	2	3	3	3
·21	1622	1626	1629	1633	1637	1641	1644	1648	1652	1656	0	1	1	2	2	2	3	3	3
·22	1660	1663	1667	1671	1675	1679	1683	1687	1690	1694	0	1	1	2	2	2	3	3	3
·23	1698	1702	1706	1710	1714	1718	1722	1726	1730	1734	0	1	1	2	2	2	3	3	4
·24	1738	1742	1746	1750	1754	1758	1762	1766	1770	1774	0	1	1	2	2	2	3	3	4
·25	1778	1782	1786	1791	1795	1799	1803	1807	1811	1816	0	1	1	2	2	2	3	3	4
·26	1820	1824	1828	1832	1837	1841	1845	1849	1854	1858	0	1	1	2	2	3	3	3	4
·27	1862	1866	1871	1875	1879	1884	1888	1892	1897	1901	0	1	1	2	2	3	3	3	4
·28	1905	1910	1914	1919	1923	1928	1932	1936	1941	1945	0	1	1	2	2	3	3	4	4
·29	1950	1954	1959	1963	1968	1972	1977	1982	1986	1991	0	1	1	2	2	3	3	4	4
·30	1995	2000	2004	2009	2014	2018	2023	2028	2032	2037	0	1	1	2	2	3	3	4	4
·31	2042	2046	2051	2056	2061	2065	2070	2075	2080	2084	0	1	1	2	2	3	3	4	4
·32	2089	2094	2099	2104	2109	2113	2118	2123	2128	2133	0	1	1	2	2	3	3	4	4
·33	2138	2143	2148	2153	2158	2163	2168	2173	2178	2183	0	1	1	2	2	3	3	4	4
·34	2188	2193	2198	2203	2208	2213	2218	2223	2228	2234	1	1	2	2	3	3	4	4	5
·35	2239	2244	2249	2254	2259	2265	2270	2275	2280	2286	1	1	2	2	3	3	4	4	5
·36	2291	2296	2301	2307	2312	2317	2323	2328	2333	2339	1	1	2	2	3	3	4	4	5
·37	2344	2350	2355	2360	2366	2371	2377	2382	2388	2393	1	1	2	2	3	3	4	4	5
·38	2399	2404	2410	2415	2421	2427	2432	2438	2443	2449	1	1	2	2	3	3	4	4	5
·39	2455	2460	2466	2472	2477	2483	2489	2495	2500	2506	1	1	2	2	3	3	4	5	5
·40	2512	2518	2523	2529	2535	2541	2547	2553	2559	2564	1	1	2	2	3	4	4	5	5
·41	2570	2576	2582	2588	2594	2600	2606	2612	2618	2624	1	1	2	2	3	4	4	5	5
·42	2630	2636	2642	2649	2655	2661	2667	2673	2679	2685	1	1	2	2	3	4	4	5	6
·43	2692	2698	2704	2710	2716	2723	2729	2735	2742	2748	1	1	2	3	3	4	4	5	6
·44	2754	2761	2767	2773	2780	2786	2793	2799	2805	2812	1	1	2	3	3	4	4	5	6
·45	2818	2825	2831	2838	2844	2851	2858	2864	2871	2877	1	1	2	3	3	4	5	5	6
·46	2884	2891	2897	2904	2911	2917	2924	2931	2938	2944	1	1	2	3	3	4	5	5	6
·47	2951	2958	2965	2972	2979	2985	2992	2999	3006	3013	1	1	2	3	3	4	5	5	6
·48	3020	3027	3034	3041	3048	3055	3062	3069	3076	3083	1	1	2	3	4	4	5	6	6
·49	3090	3097	3105	3112	3119	3126	3133	3141	3148	3155	1	1	2	3	4	4	5	6	6

	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
·50	3162	3170	3177	3184	3192	3199	3206	3214	3221	322?	1	1	2	3	4	4	5	6	7
·51	3236	3243	3251	3258	3266	3273	3281	3289	3296	3304	1	2	2	3	4	5	5	6	7
·52	3311	3319	3327	3334	3342	3350	3357	3365	3373	3381	1	2	2	3	4	5	5	6	7
·53	3388	3396	3404	3412	3420	3428	3436	3443	3451	3459	1	2	2	3	4	5	6	6	7
·54	3467	3475	3483	3491	3499	3508	3516	3524	3532	3540	1	2	2	3	4	5	6	6	7
·55	3548	3556	3565	3573	3581	3589	3597	3606	3614	3622	1	2	2	3	4	5	6	7	7
·56	3631	3639	3648	3656	3664	3673	3681	3690	3698	3707	1	2	3	3	4	5	6	7	8
·57	3715	3724	3733	3741	3750	3758	3767	3776	3784	3793	1	2	3	3	4	5	6	7	8
·58	3802	3811	3819	3828	3837	3846	3855	3864	3873	3882	1	2	3	4	4	5	6	7	8
·59	3890	3899	3908	3917	3926	3936	3945	3954	3963	3972	1	2	3	4	5	5	6	7	8
·60	3981	3990	3999	4009	4018	4027	4036	4046	4055	4064	1	2	3	4	5	6	6	7	8
·61	4074	4083	4093	4102	4111	4121	4130	4140	4150	4159	1	2	3	4	5	6	7	8	9
·62	4169	4178	4188	4198	4207	4217	4227	4236	4246	4256	1	2	3	4	5	6	7	8	9
·63	4266	4276	4285	4295	4305	4315	4325	4335	4345	4355	1	2	3	4	5	6	7	8	9
·64	4365	4375	4385	4395	4406	4416	4426	4436	4446	4457	1	2	3	4	5	6	7	8	9
·65	4467	4477	4487	4498	4508	4519	4529	4539	4550	4560	1	2	3	4	5	6	7	8	9
·66	4571	4581	4592	4603	4613	4624	4634	4645	4656	4667	1	2	3	4	5	6	7	9	10
·67	4677	4688	4699	4710	4721	4732	4742	4753	4764	4775	1	2	3	4	5	7	8	9	10
·68	4786	4797	4808	4819	4831	4842	4853	4864	4875	4887	1	2	3	4	6	7	8	9	10
·69	4898	4909	4920	4932	4943	4955	4966	4977	4989	5000	1	2	3	5	6	7	8	9	10
·70	5012	5023	5035	5047	5058	5070	5082	5093	5105	5117	1	2	4	5	6	7	8	9	11
·71	5129	5140	5152	5164	5176	5188	5200	5212	5224	5236	1	2	4	5	6	7	8	10	11
·72	5248	5260	5272	5284	5297	5309	5321	5333	5346	5358	1	2	4	5	6	7	9	10	11
·73	5370	5383	5395	5408	5420	5433	5445	5458	5470	5483	1	3	4	5	6	8	9	10	11
·74	5495	5508	5521	5534	5546	5559	5572	5585	5598	5610	1	3	4	5	6	8	9	10	12
·75	5623	5636	5649	5662	5675	5689	5702	5715	5728	5741	1	3	4	5	7	8	9	10	12
·76	5754	5768	5781	5794	5808	5821	5834	5848	5861	5875	1	3	4	5	7	8	9	11	12
·77	5888	5902	5916	5929	5943	5957	5970	5984	5998	6012	1	3	4	5	7	8	10	11	12
·78	6026	6039	6053	6067	6081	6095	6109	6124	6138	6152	1	3	4	6	7	8	10	11	13
·79	6166	6180	6194	6209	6223	6237	6252	6266	6281	6295	1	3	4	6	7	9	10	11	13
·80	6310	6324	6339	6353	6368	6383	6397	6412	6427	6442	1	3	4	6	7	9	10	12	13
·81	6457	6471	6486	6501	6516	6531	6546	6561	6577	6592	2	3	5	6	8	9	11	12	14
·82	6607	6622	6637	6653	6668	6683	6699	6714	6730	6745	2	3	5	6	8	9	11	12	14
·83	6761	6776	6792	6808	6823	6839	6855	6871	6887	6902	2	3	5	6	8	9	11	13	14
·84	6918	6934	6950	6966	6982	6998	7015	7031	7047	7063	2	3	5	6	8	10	11	13	15
·85	7079	7096	7112	7129	7145	7161	7178	7194	7211	7228	2	3	5	7	8	10	12	13	15
·86	7244	7261	7278	7295	7311	7328	7345	7362	7379	7396	2	3	5	7	8	10	12	13	15
·87	7413	7430	7447	7464	7482	7499	7516	7534	7551	7568	2	4	5	7	9	10	12	14	16
·88	7586	7603	7621	7638	7656	7674	7691	7709	7727	7745	2	4	5	7	9	11	12	14	16
·89	7762	7780	7798	7816	7834	7852	7870	7889	7907	7925	2	4	5	7	9	11	13	14	16
·90	7943	7962	7980	7998	8017	8035	8054	8072	8091	8110	2	4	6	7	9	11	13	15	17
·91	8128	8147	8166	8185	8204	8222	8241	8260	8279	8299	2	4	6	8	9	11	13	15	17
·92	8318	8337	8356	8375	8395	8414	8433	8453	8472	8492	2	4	6	8	10	12	14	15	17
·93	8511	8531	8551	8570	8590	8610	8630	8650	8670	8690	2	4	6	8	10	12	14	16	18
·94	8710	8730	8750	8770	8790	8810	8831	8851	8872	8892	2	4	6	8	10	12	14	16	18
·95	8913	8933	8954	8974	8995	9016	9036	9057	9078	9099	2	4	6	8	10	12	15	17	19
·96	9120	9141	9162	9183	9204	9226	9247	9268	9290	9311	2	4	6	8	11	13	15	17	19
·97	9333	9354	9376	9397	9419	9441	9462	9484	9506	9528	2	4	7	9	11	13	15	17	20
·98	9550	9572	9594	9616	9638	9661	9683	9705	9727	9750	2	4	7	9	11	13	16	18	20
·99	9772	9795	9817	9840	9863	9886	9908	9931	9954	9977	2	5	7	9	11	14	16	18	20

TABLE 8
TRIGONOMETRIC FUNCTIONS

ANGLE		Chord.	Sine.	Tangent.	Co-Tangent.	Cosine.	1·414	1·5708	90°
Deg.	Radians.								
0°	0	0	0	0	Infinite.	1	1·414	1·5708	90°
1	0·0175	0·017	0·0175	0·0175	57·2900	0·9998	1·402	1·5533	89
2	0·0349	0·035	0·0349	0·0349	28·6363	0·9994	1·389	1·5359	88
3	0·0524	0·052	0·0523	0·0524	19·0811	0·9986	1·377	1·5184	87
4	0·0698	0·070	0·0698	0·0699	14·3007	0·9976	1·364	1·5010	86
5	0·0873	0·087	0·0872	0·0875	11·4301	0·9962	1·351	1·4835	85
6	0·1047	0·105	0·1045	0·1051	9·5144	0·9945	1·338	1·4661	84
7	0·1222	0·122	0·1219	0·1228	8·1443	0·9925	1·325	1·4486	83
8	0·1396	0·140	0·1392	0·1405	7·1154	0·9903	1·312	1·4312	82
9	0·1571	0·157	0·1564	0·1584	6·3138	0·9877	1·299	1·4137	81
10	0·1745	0·174	0·1736	0·1763	5·6713	0·9848	1·286	1·3963	80
11	0·1920	0·192	0·1908	0·1944	5·1446	0·9816	1·272	1·3788	79
12	0·2094	0·209	0·2079	0·2126	4·7046	0·9781	1·259	1·3614	78
13	0·2269	0·226	0·2250	0·2309	4·3315	0·9744	1·245	1·3439	77
14	0·2443	0·244	0·2419	0·2493	4·0108	0·9703	1·231	1·3265	76
15	0·2618	0·261	0·2588	0·2679	3·7321	0·9659	1·218	1·3090	75
16	0·2793	0·278	0·2756	0·2867	3·4874	0·9613	1·204	1·2915	74
17	0·2967	0·296	0·2924	0·3057	3·2709	0·9563	1·190	1·2741	73
18	0·3142	0·313	0·3090	0·3249	3·0777	0·9511	1·176	1·2566	72
19	0·3316	0·330	0·3256	0·3443	2·9042	0·9455	1·161	1·2392	71
20	0·3491	0·347	0·3420	0·3640	2·7475	0·9397	1·147	1·2217	70

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TABLE 8 (continued)

Deg.			Cosine.	Co-Tangent.	Tangent.	Sine.	Chord.	Radians. ANGLE	Deg.
21	0·3665	0·364	0·3584	0·3839	2·6051	0·9336	1·133	1·2043	69
22	0·3840	0·382	0·3746	0·4040	2·4751	0·9272	1·118	1·1868	68
23	0·4014	0·399	0·3907	0·4245	2·3559	0·9205	1·104	1·1694	67
24	0·4189	0·416	0·4067	0·4452	2·2460	0·9135	1·089	1·1519	66
25	0·4363	0·433	0·4226	0·4663	2·1445	0·9063	1·075	1·1345	65
26	0·4538	0·450	0·4384	0·4877	2·0503	0·8988	1·060	1·1170	64
27	0·4712	0·467	0·4540	0·5095	1·9626	0·8910	1·045	1·0996	63
28	0·4887	0·484	0·4695	0·5317	1·8807	0·8889	1·030	1·0821	62
29	0·5061	0·501	0·4848	0·5543	1·8040	0·8746	1·015	1·0647	61
30	0·5236	0·518	0·5000	0·5774	1·7321	0·8660	1·000	1·0472	60
31	0·5411	0·534	0·5150	0·6009	1·6643	0·8572	0·985	1·0297	59
32	0·5585	0·551	0·5299	0·6249	1·6003	0·8480	0·970	1·0123	58
33	0·5760	0·568	0·5446	0·6494	1·5399	0·8387	0·954	0·9948	57
34	0·5934	0·585	0·5592	0·6745	1·4826	0·8290	0·939	0·9774	56
35	0·6109	0·601	0·5736	0·7002	1·4281	0·8192	0·923	0·9599	55
36	0·6283	0·618	0·5878	0·7265	1·3764	0·8090	0·908	0·9425	54
37	0·6458	0·635	0·6018	0·7536	1·3270	0·7986	0·892	0·9250	53
38	0·6632	0·651	0·6157	0·7813	1·2799	0·7880	0·877	0·9076	52
39	0·6807	0·668	0·6293	0·8098	1·2349	0·7771	0·861	0·8901	51
40	0·6981	0·684	0·6428	0·8391	1·1918	0·7660	0·845	0·8727	50
41	0·7156	0·700	0·6561	0·8693	1·1504	0·7547	0·829	0·8552	49
42	0·7330	0·717	0·6691	0·9004	1·1106	0·7431	0·813	0·8378	48
43	0·7505	0·733	0·6820	0·9325	1·0724	0·7313	0·797	0·8203	47
44	0·7679	0·749	0·6947	0·9675	1·0355	0·7193	0·781	0·8029	46
45°	0·7854	0·765	0·7071	1·0000	1·0000	0·7071	0·765	0·7854	45°

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